A Field Experiment to Study the Atmosphere Over Steep Alpine Environments

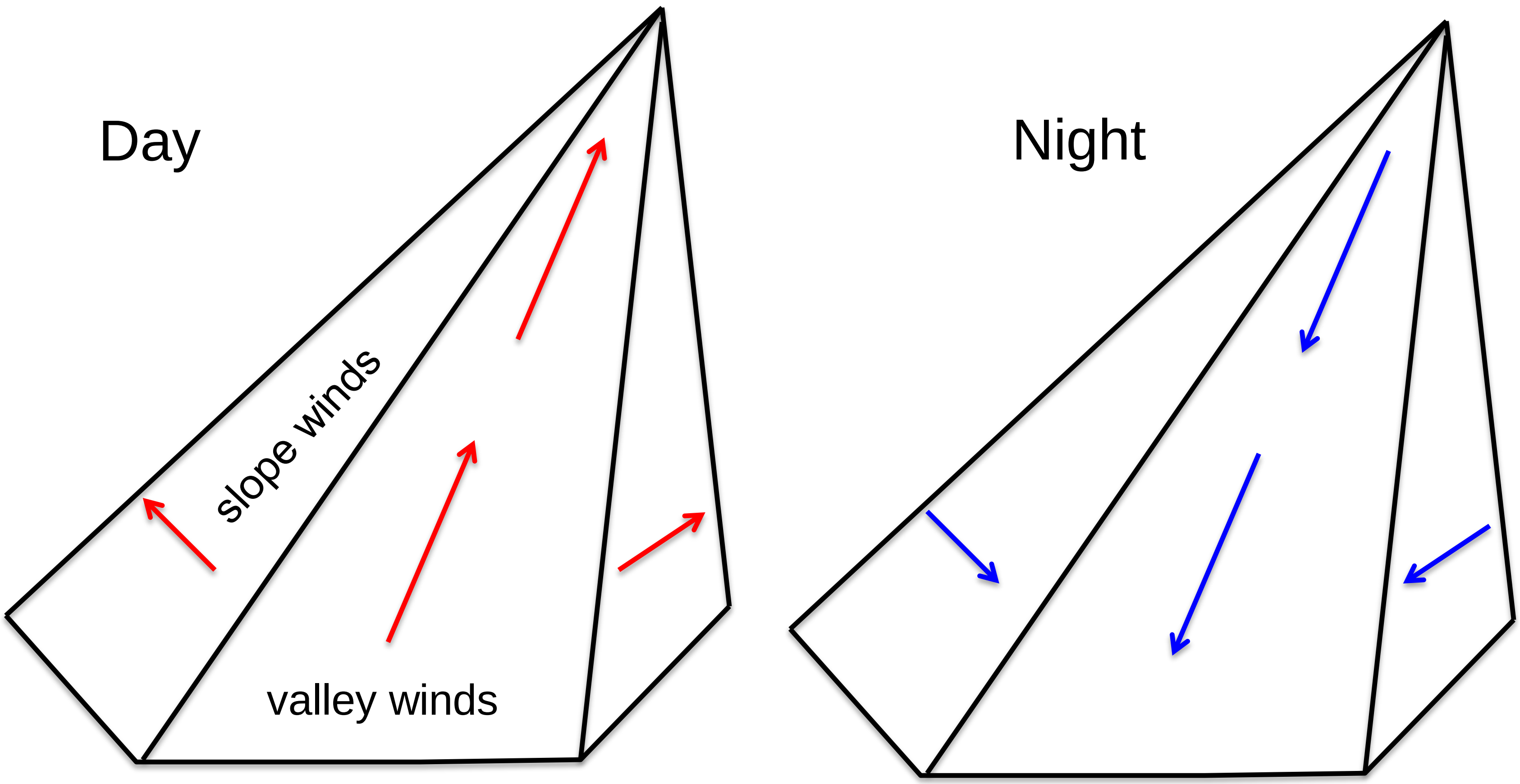
Daniel Nadeau

ER Pardyjak, CW Higgins, HH Huwald, F Bärenbold, E Sauthier, MB Parlange


60% of Switzerland’s surface
is covered with mountains
How well do we understand thermal atmospheric circulations
over this complex terrain?

Introduction

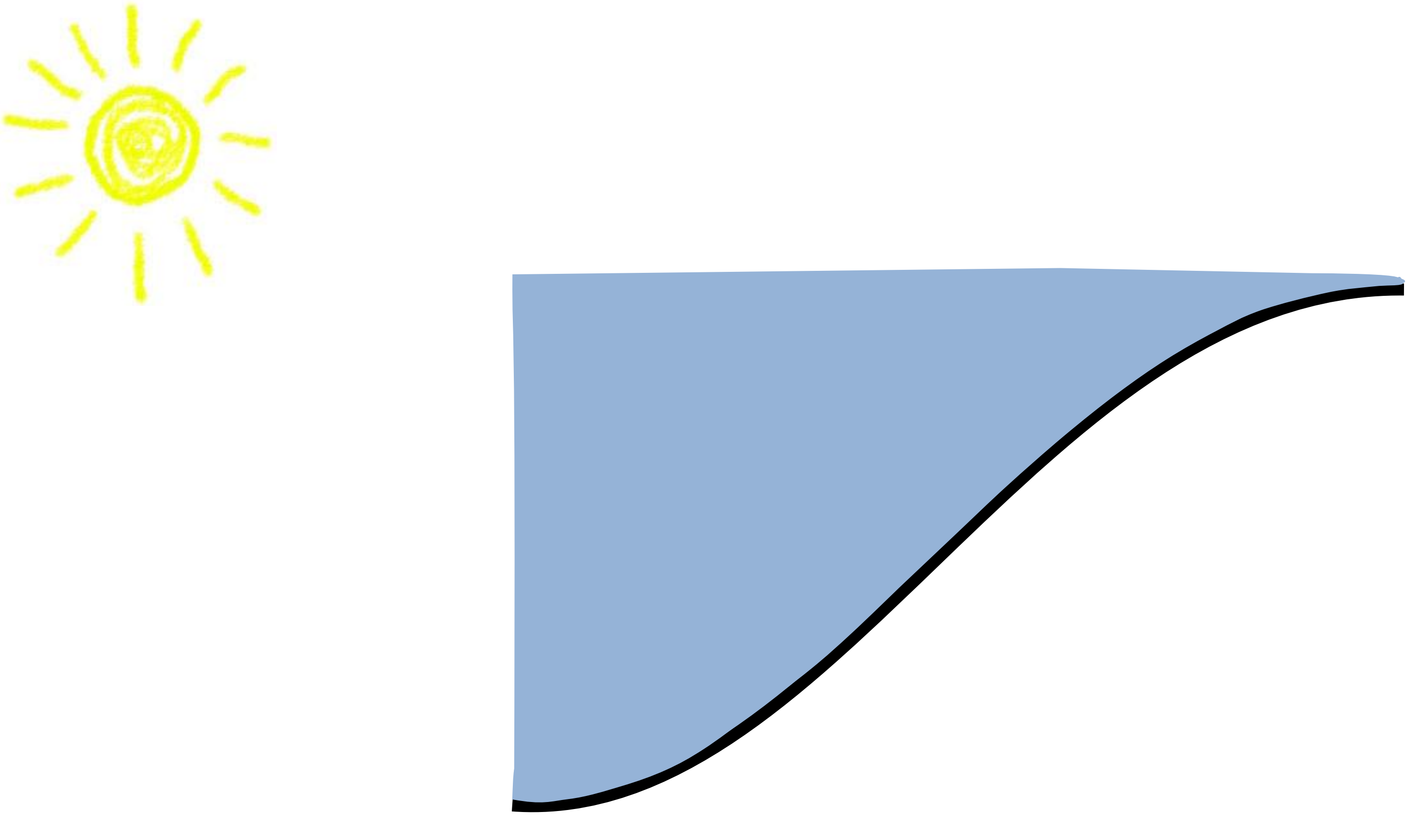
Clear sky conditions in summertime



Adapted from (Whiteman, 2000)

Introduction

How <u>anabatic</u> (upslope) winds are formed



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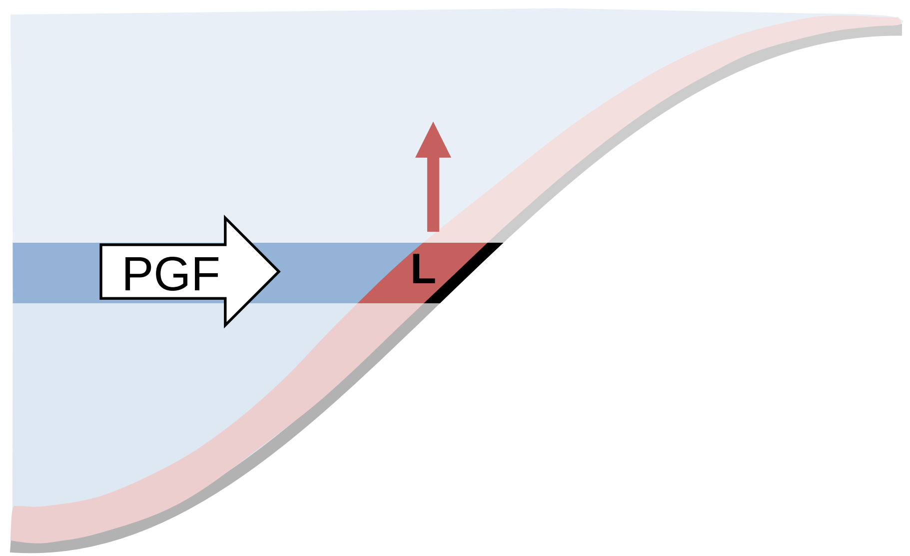
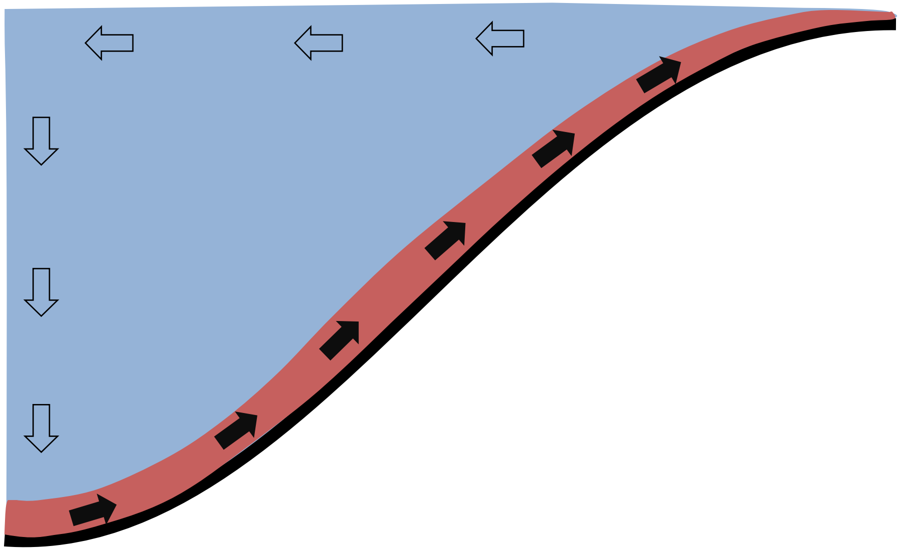


PGF: pressure gradient force

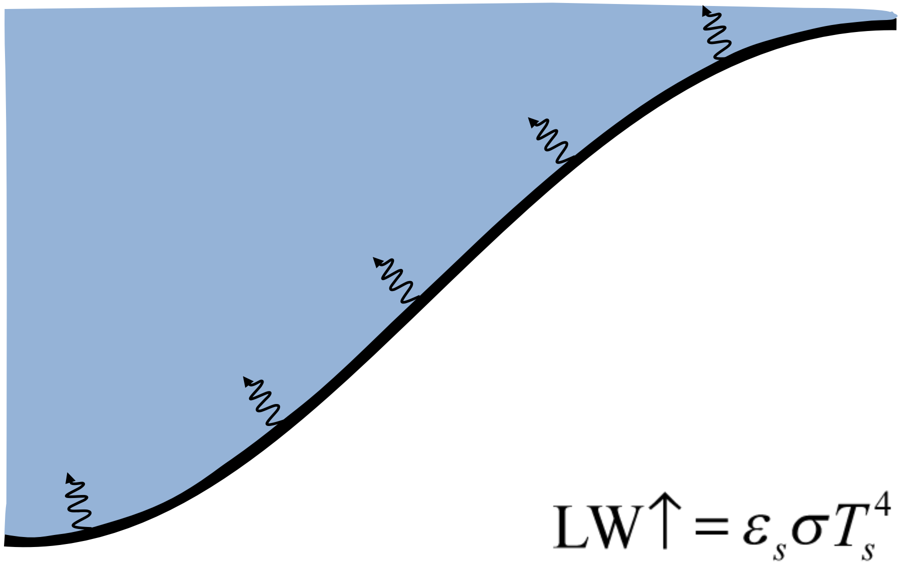
Introduction

How <u>anabatic</u> (upslope) winds are formed



Introduction

How <u>katabatic</u> (downslope) winds are formed



$$\mathrm{LW}\uparrow = \varepsilon_s \sigma T_s^4$$

Introduction

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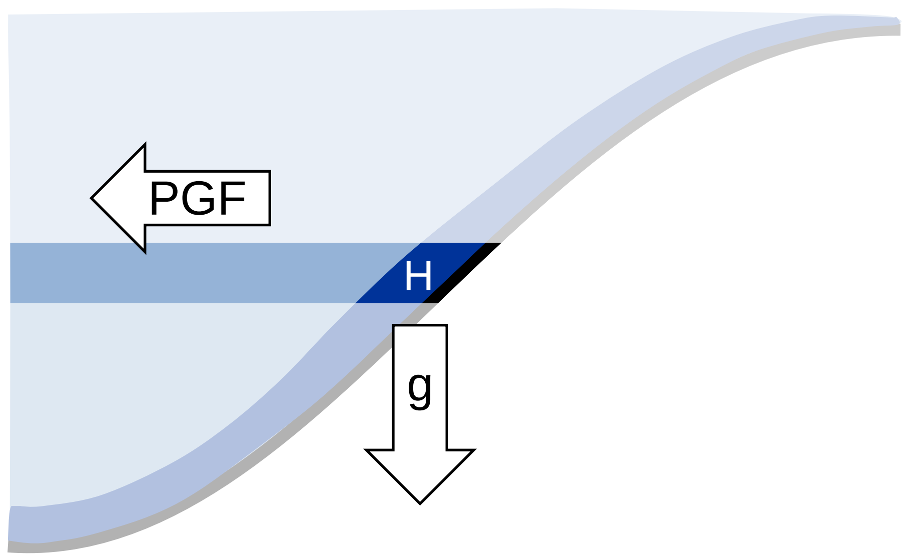

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Introduction

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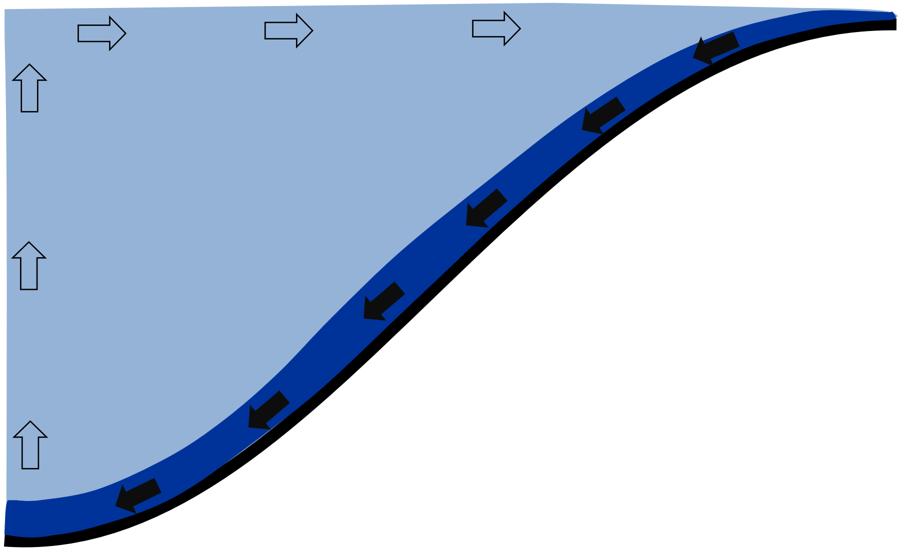
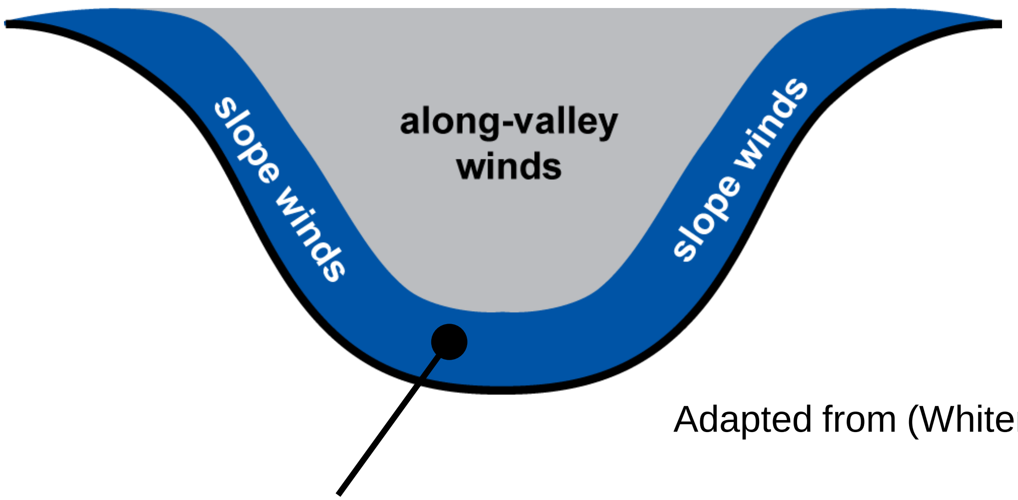


Introduction

Vertical structure of diurnal mountain winds



Adapted from (Whiteman, 2000)

Land-atmosphere interactions take place in this layer.

Understanding slope winds is crucial for hydrologic models.

Motivations

What we know:

- basic atmospheric circulations are well understood (Whiteman, 2000)
- theory and literature are mostly focused on gentle terrain and idealized slopes (Hunt et al., JFM, 2003)
- Some important field campaigns mountain winds:
    - MAP experiment
    - T-REX
    - Mt. Hymettos (Greece)

Challenges:

- thermal circulations are unsteady
- lack of theory and understanding during transition periods
- hard to monitor meteorological processes over steep terrain

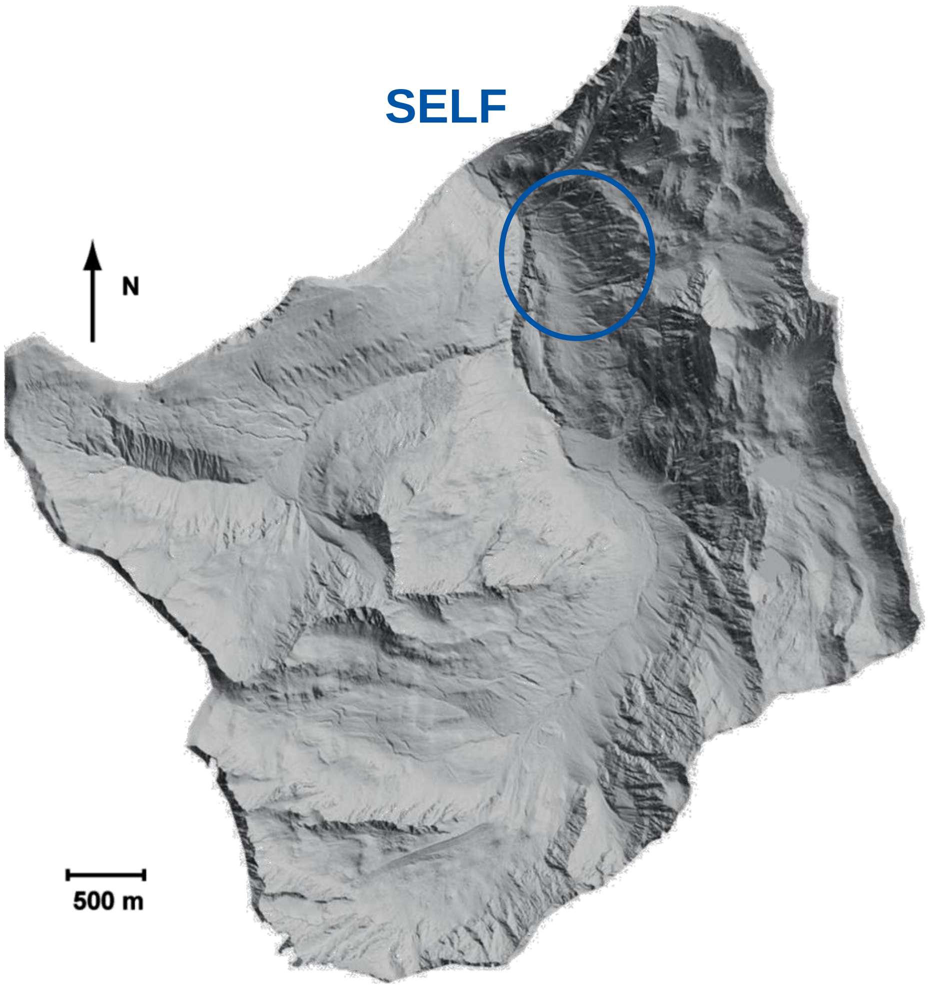
Open questions:

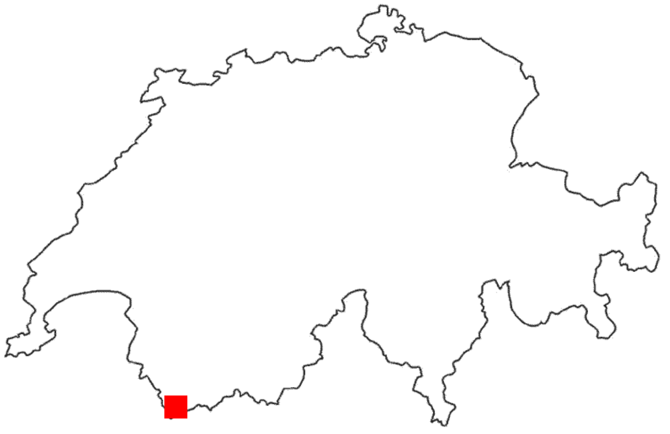
- time scales during evening transitions?
- transitioning front, from top to bottom or vice-versa?
- atmospheric response to abrupt shut-off of solar radiation?

Experimental Site

Slope Experiment at La Fouly (SELF)

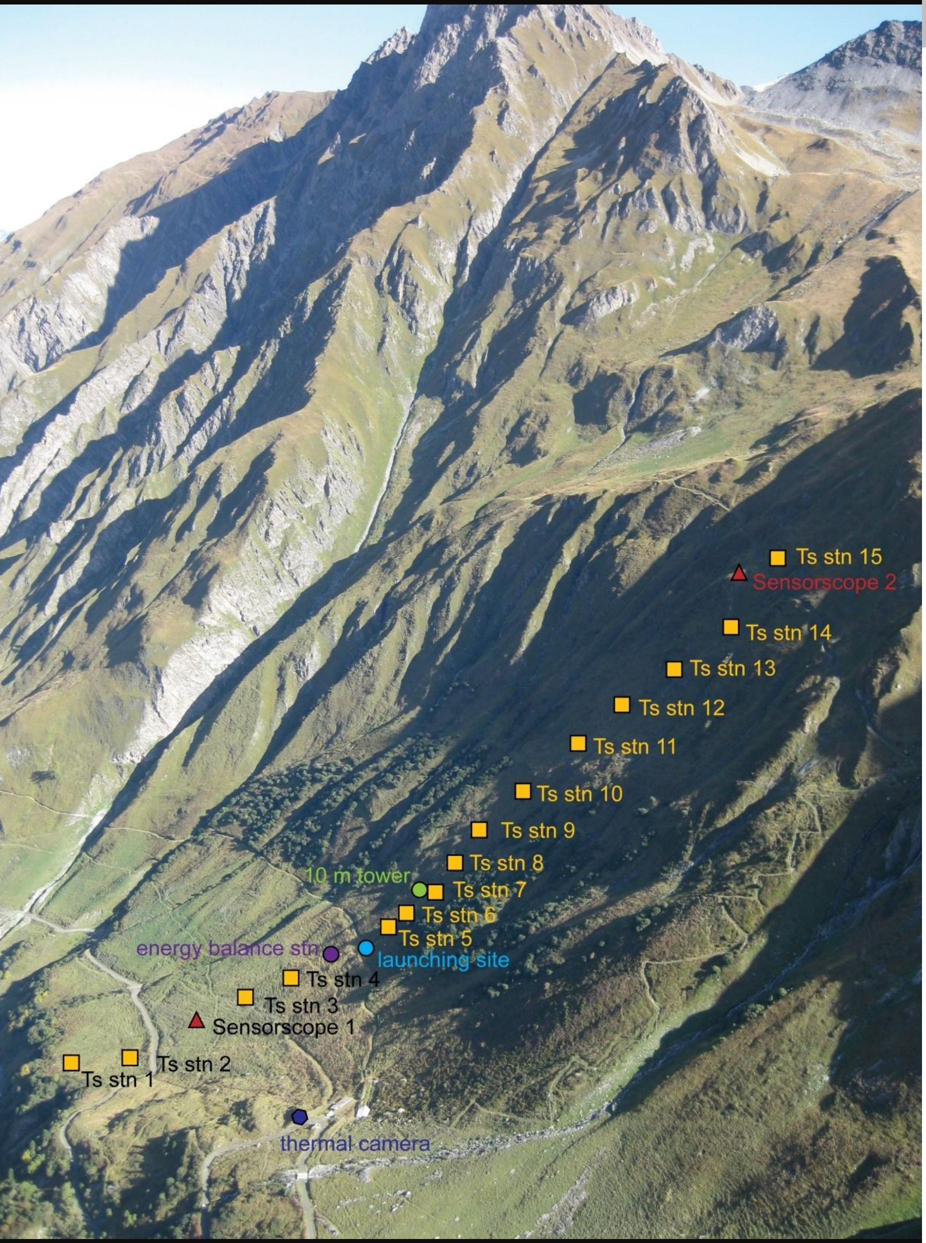
Dranse de Ferret Alpine Catchment





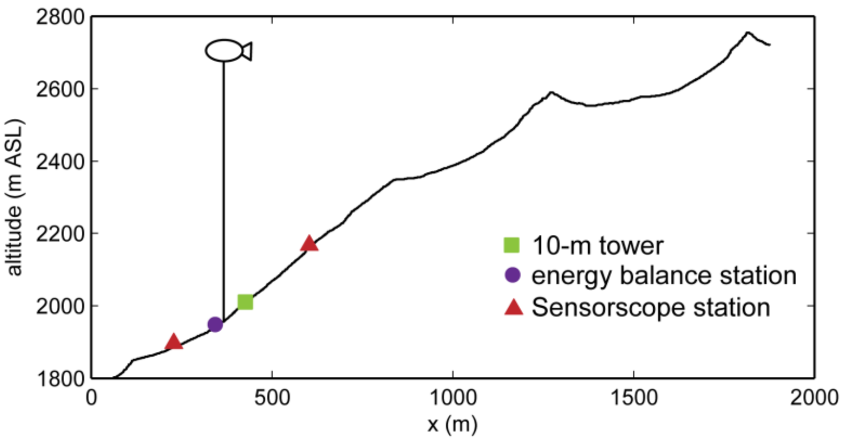
Val Ferret, Swiss Alps
45.902°N, 7.123°E
7 July to 30 Sept. 2010
West-facing slope
Altitude range: 1800 to 2200 m ASL

Experimental Setup

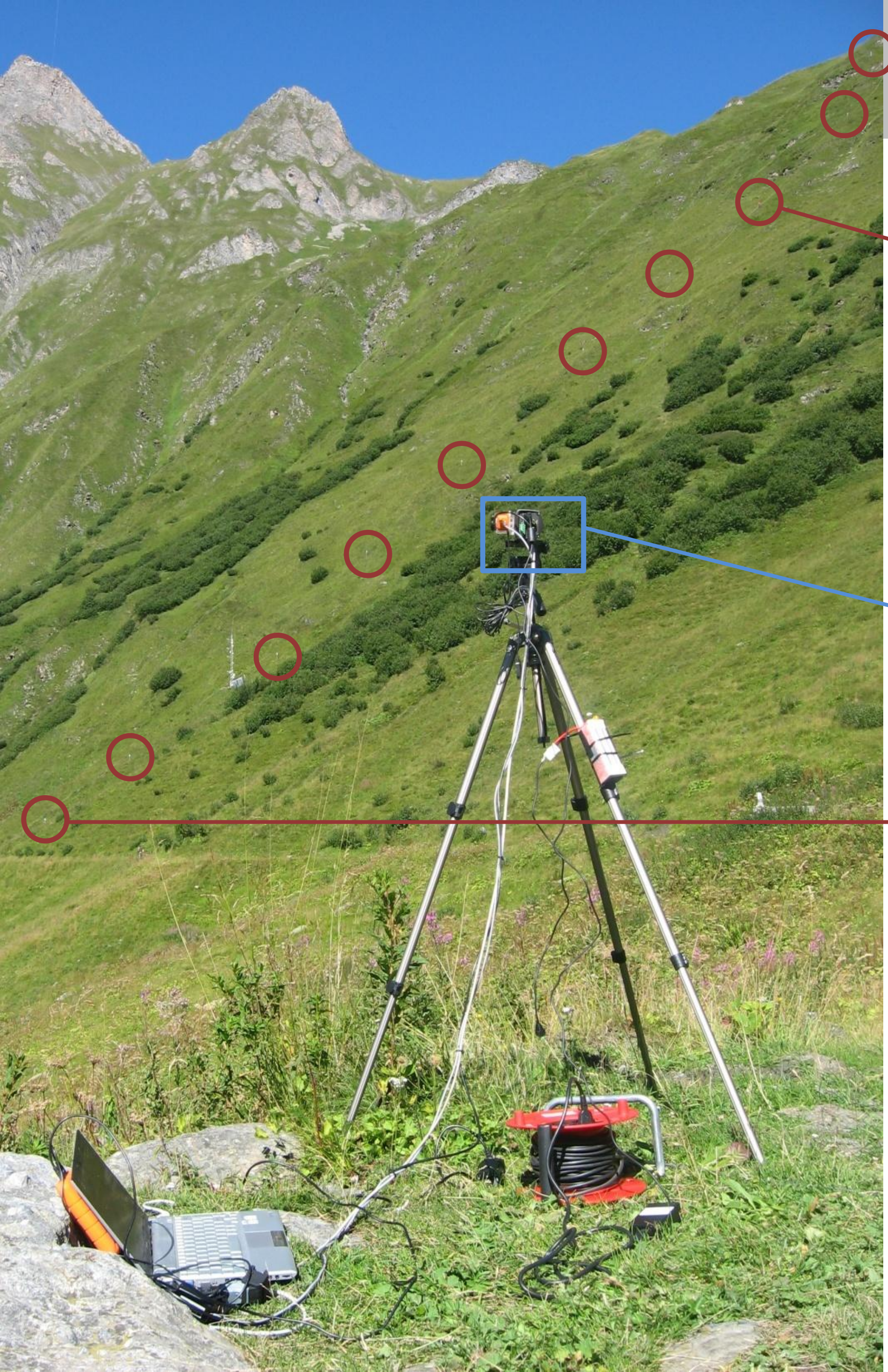


21 Sept. 2010, 09:45

- T_{sfc} stations
- thermal camera
- energy balance station
- 10 m tower
- tethered balloon
- Sensorscope stations



T_{sfc} Measurements



undergrad student

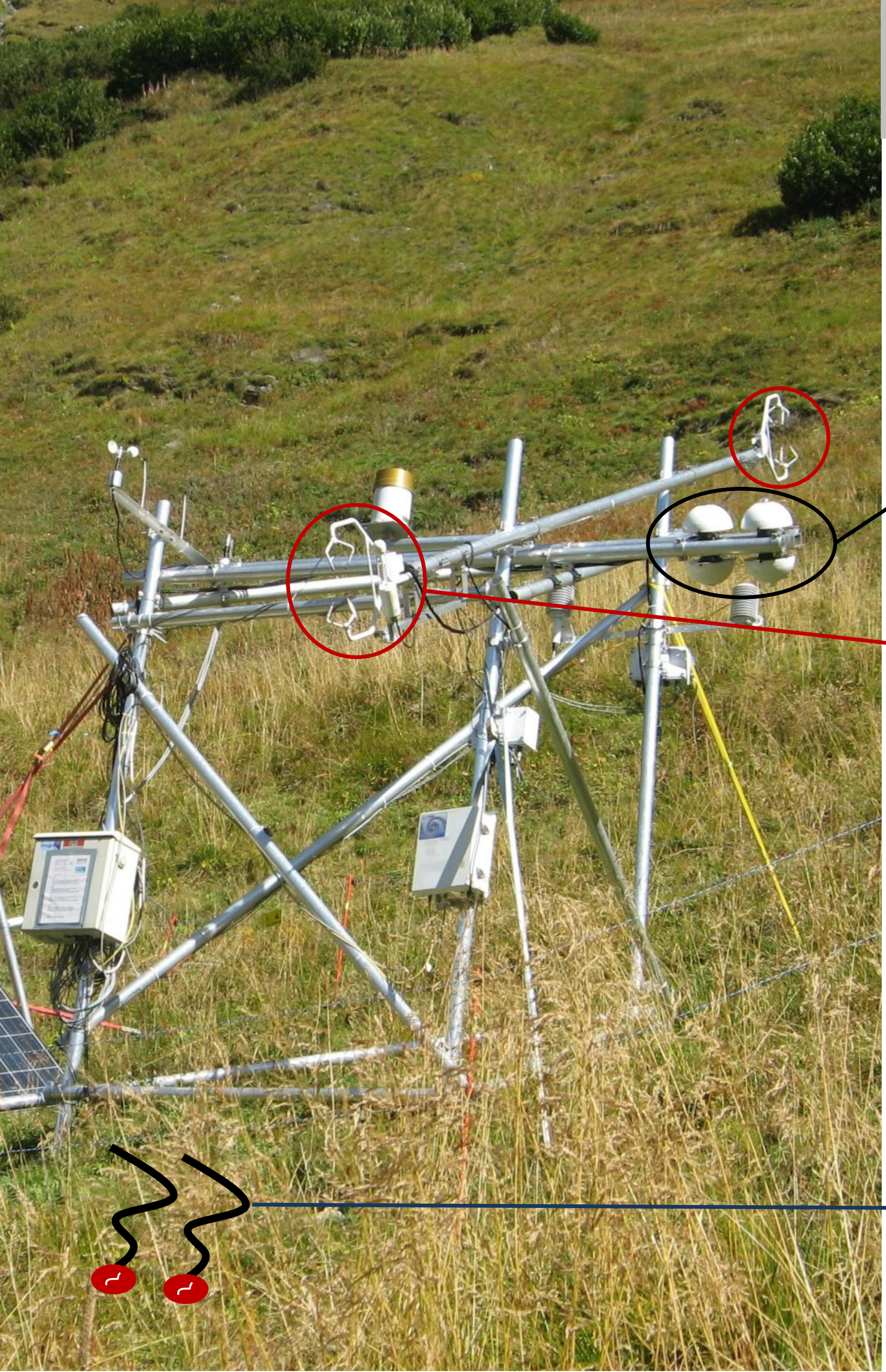
deployed during 2 IOPs (clear-sky days):
- infrared camera FLIR A320 (320 x 240 px)
- optical camera (752 x 480 px) UNIVERSITY OF CAMBRIDGE

sampling frequency: 7 Hz

surface temperature stations

(Zytemp TN901 IR sensors with Arduino boards)

Energy Balance Station (slope: 30°)

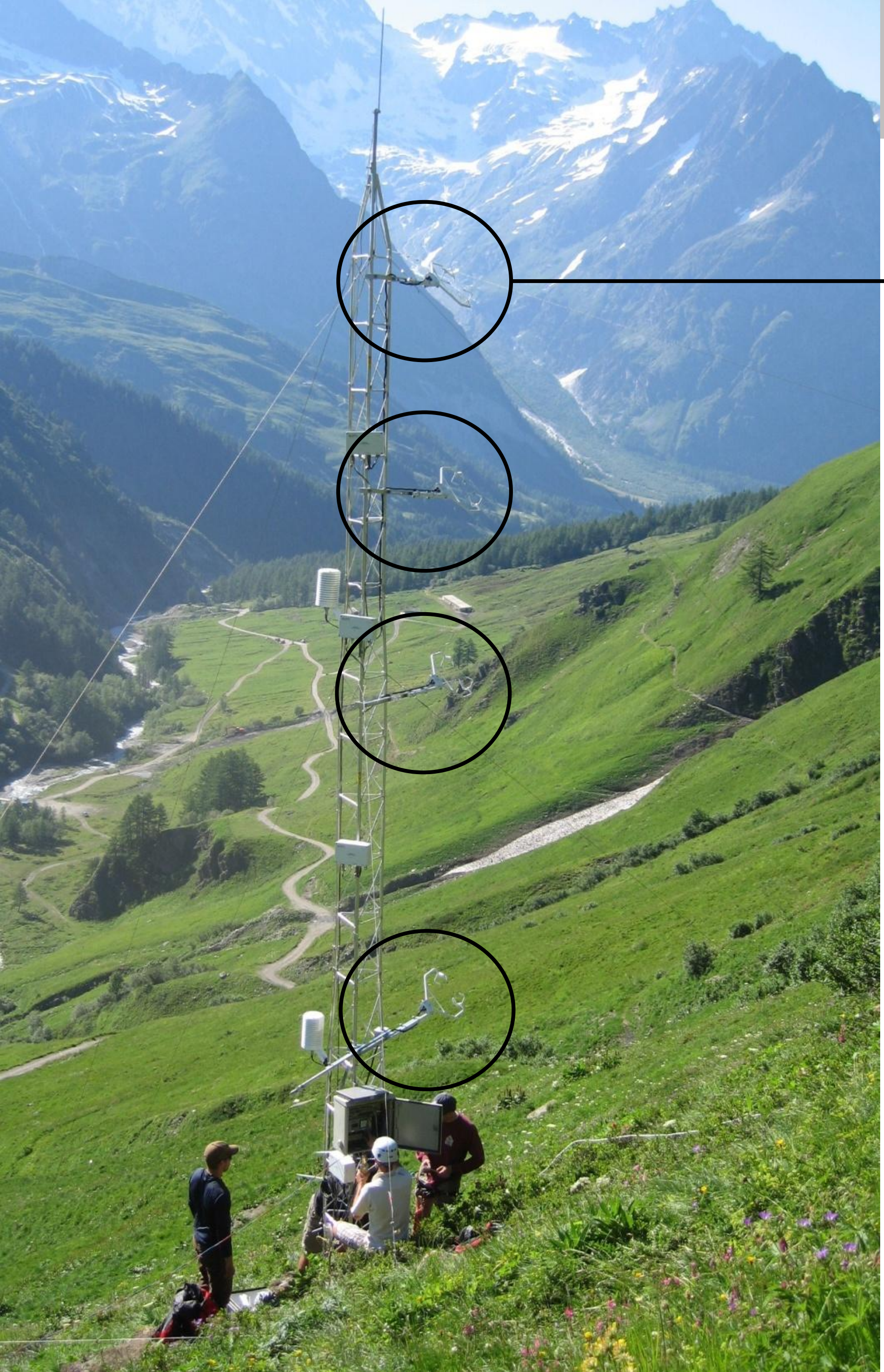


4 radiometers (LW↑, LW↓, SW↑,SW↓)
(mounted parallel to the slope)

1 open path H_2O-CO_2 analyzer
2 sonic anemometers
(axis normal to the slope)
⇨ planar fit correction

2 soil heat flux plates

10-m Tower (slope: 40°)



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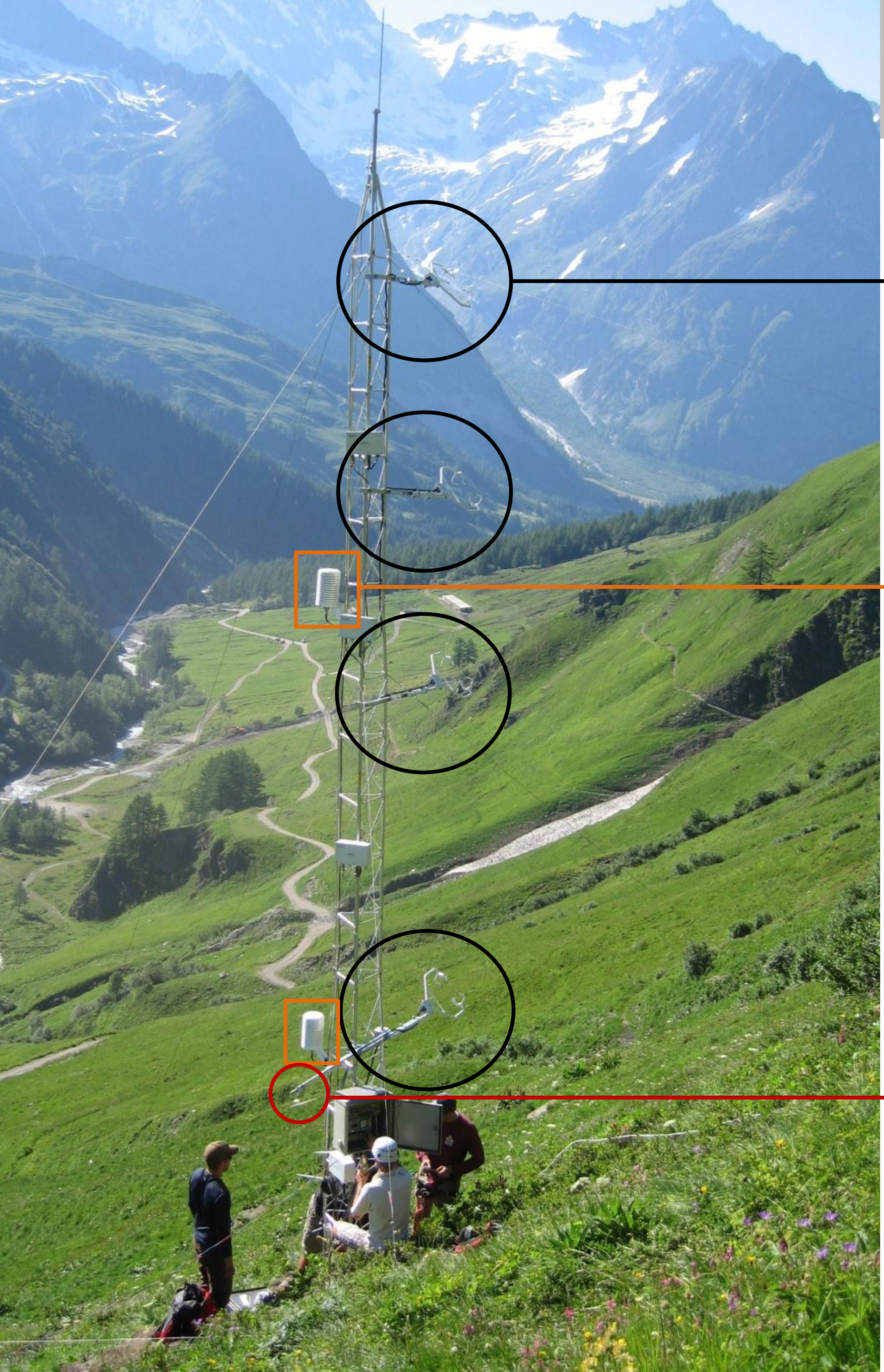


4 sonic anemometers
(axis normal to the slope)
⇨ planar fit correction

2 T + RH sensors

1 net radiometer
(axis normal to the slope)

Tethered Sonde

- deployed during 4 IOPs (clear-sky days)

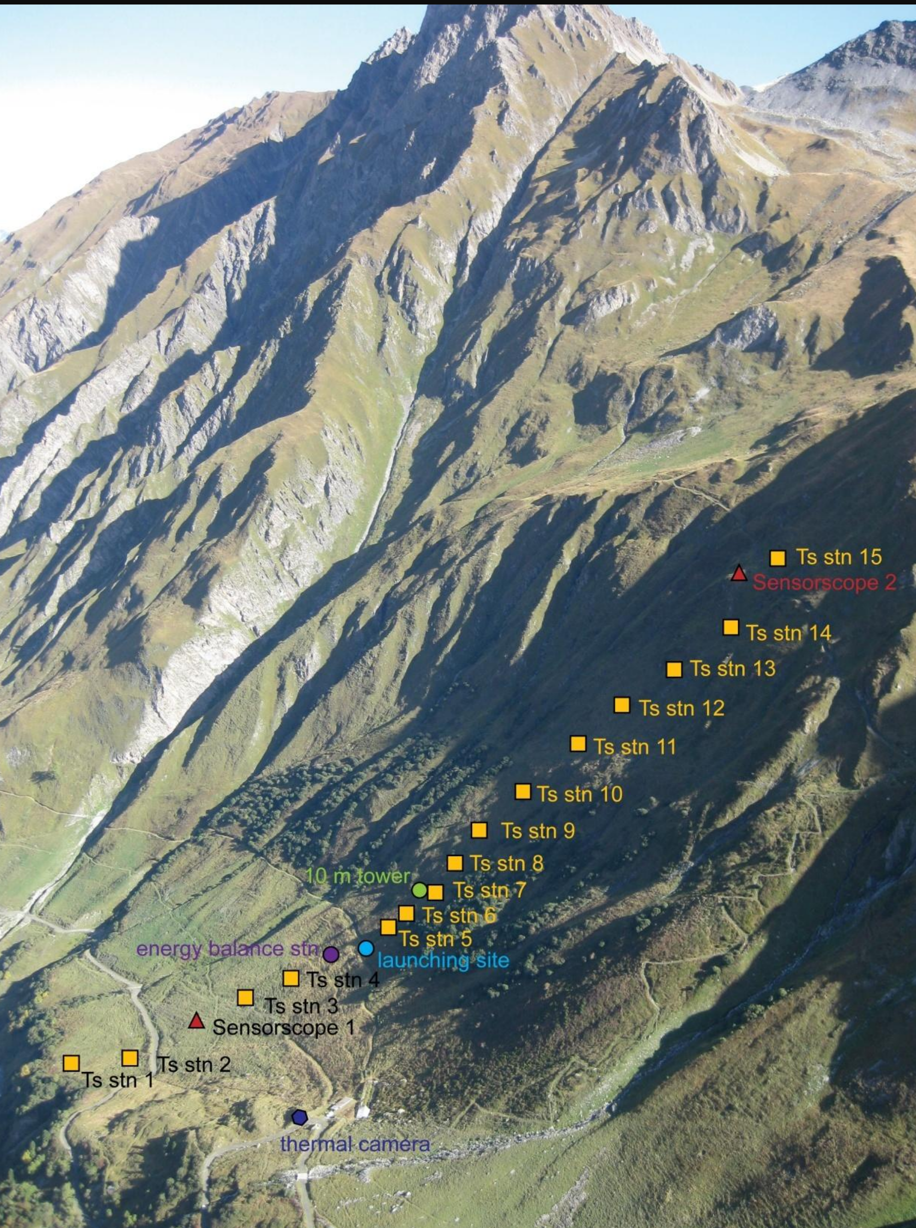
- measurements of:
  - wind speed
  - wind direction
  - air temperature
  - relative humidity

- profiles from 0 to 750 m above ground (1950 to 2700) m ASL

Sensorscope Stations

- wireless network of weather stations
- measurements of:
  - wind speed
  - wind direction
  - air temperature
  - surface temperature
  - relative humidity
  - solar radiation
  - soil moisture
- 2 stations installed on the slope
- 15 stations in the entire catchment

Experimental Setup



21 Sept. 2010, 09:45

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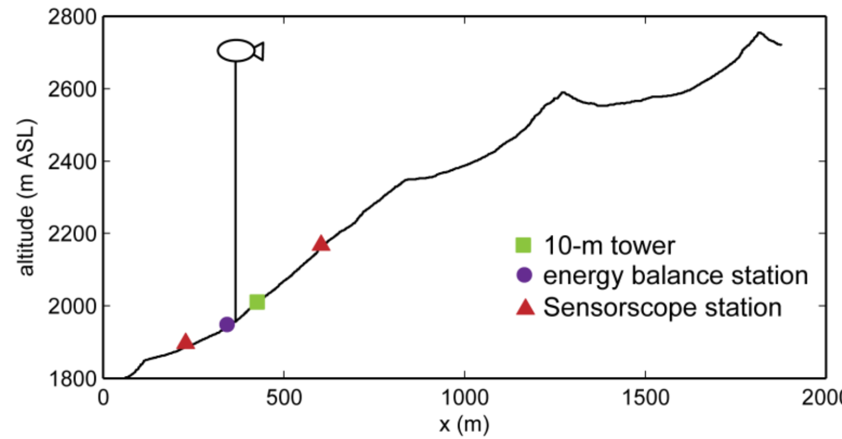
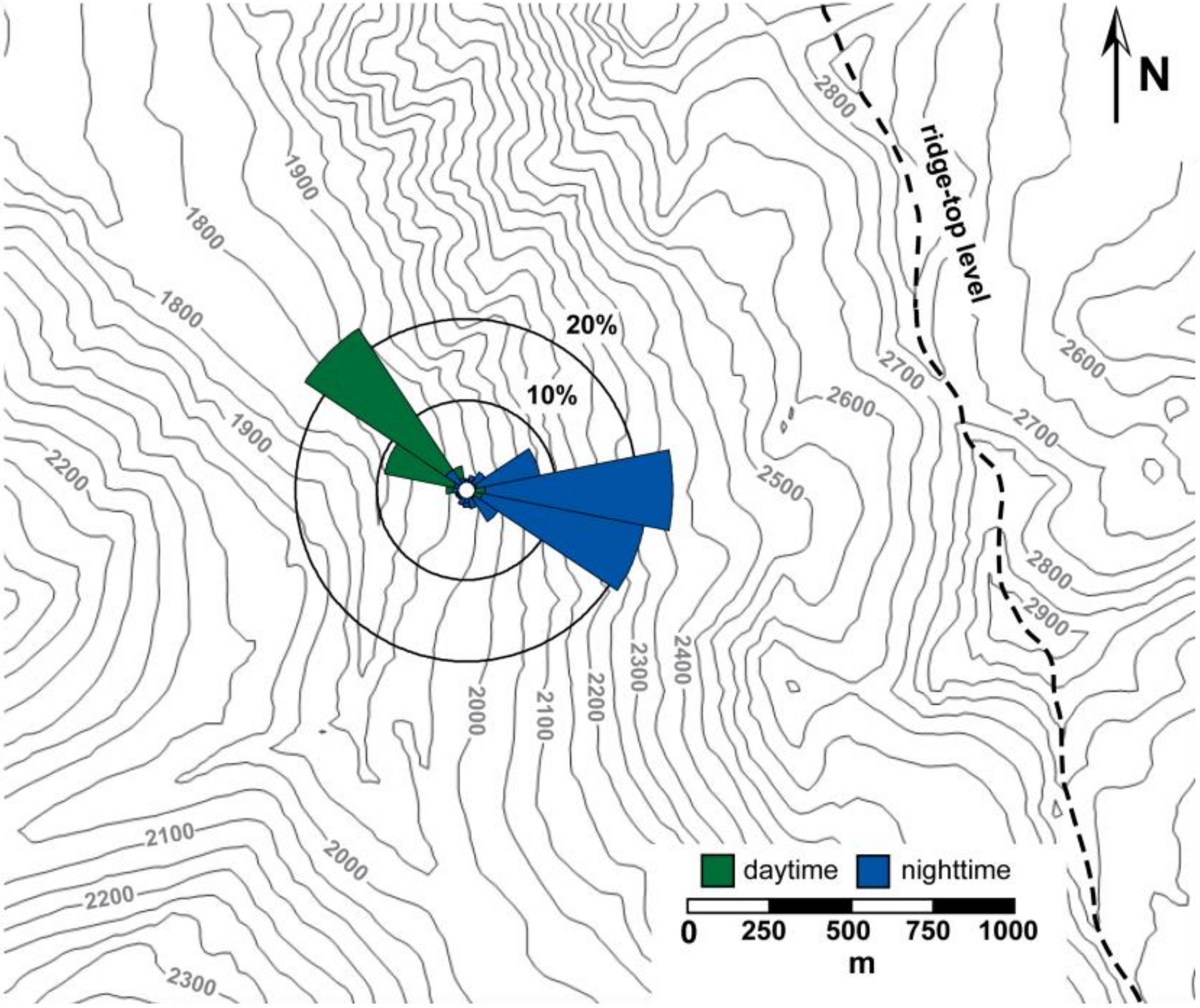
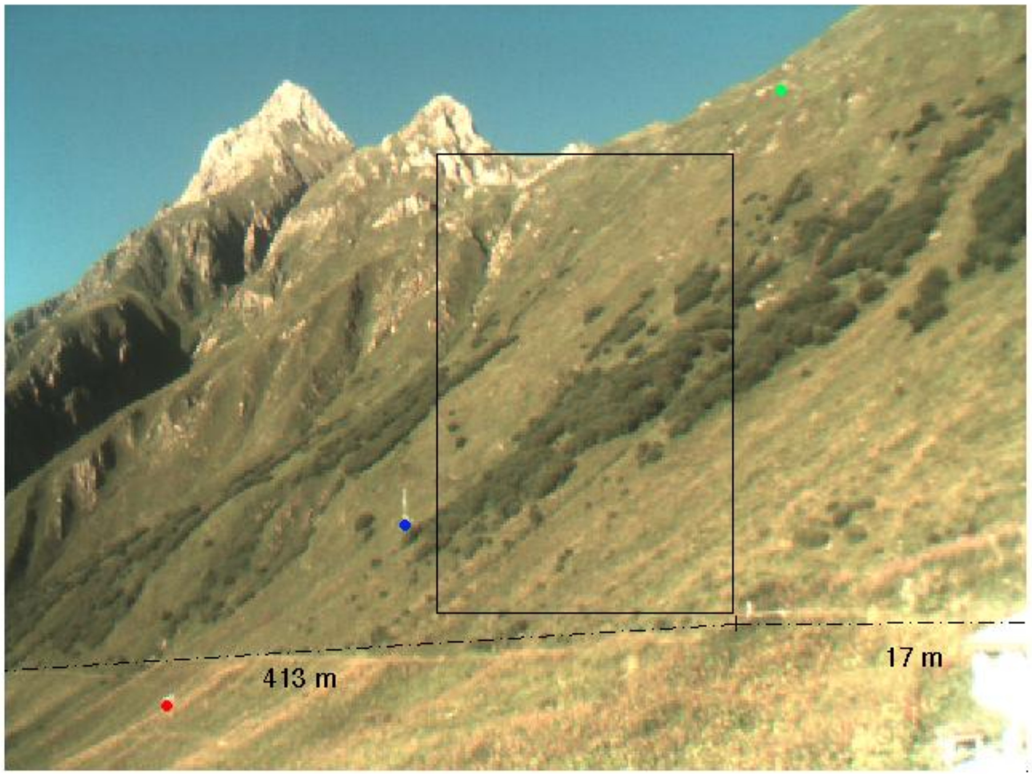


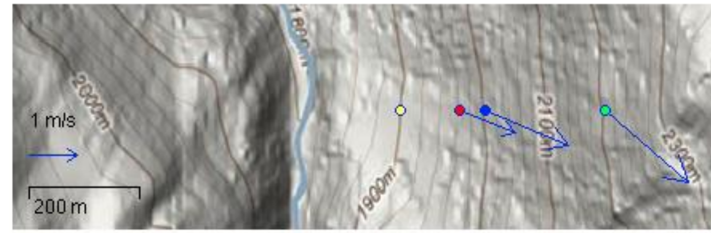
Wind Rose for Clear-Sky Days

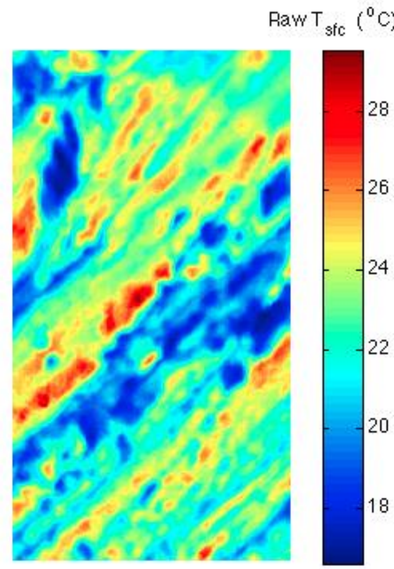


1 September 2010: The Story of an Evening Transition

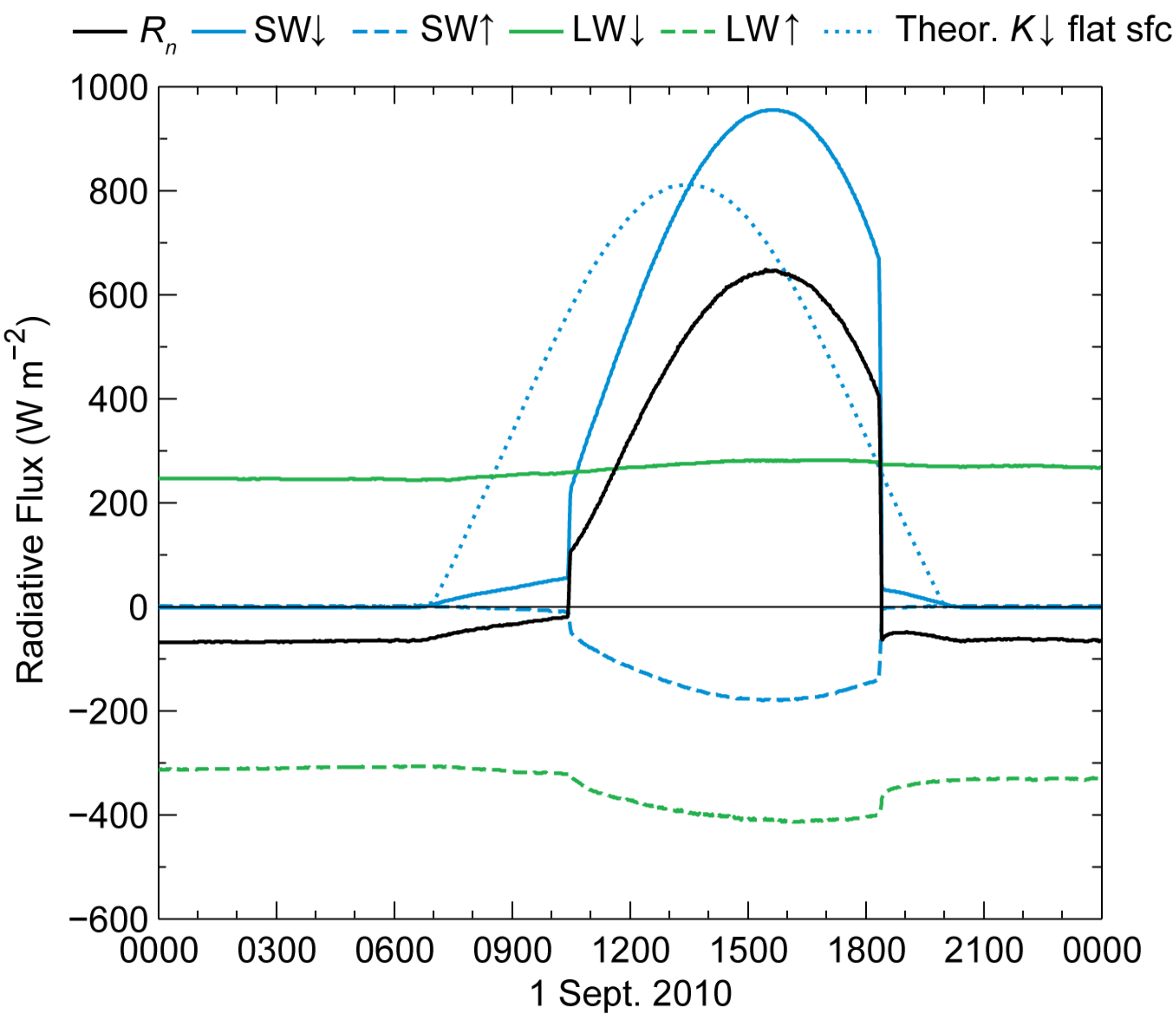
Val Ferret: 01-Sep-2010 18:00:25





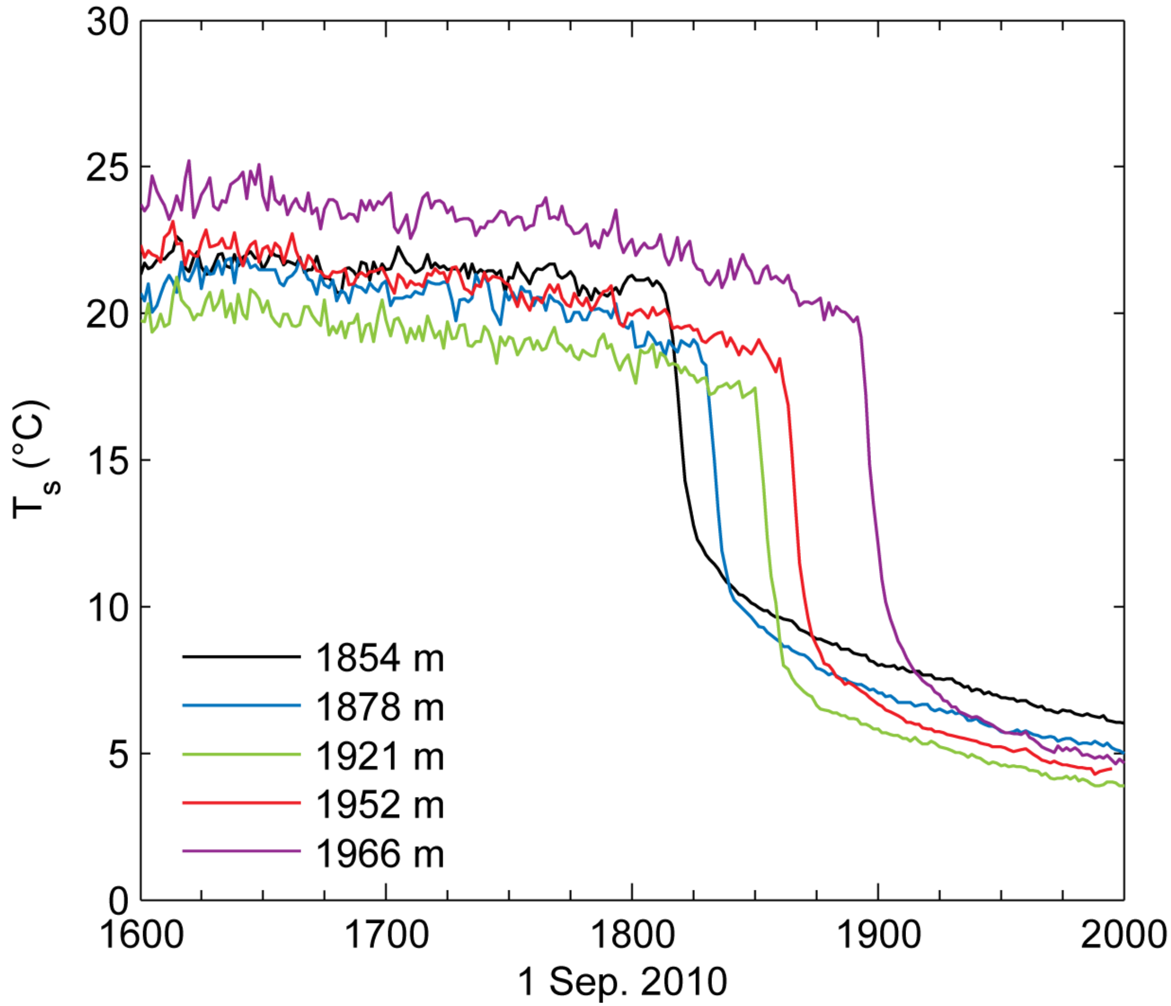


Radiation Budget



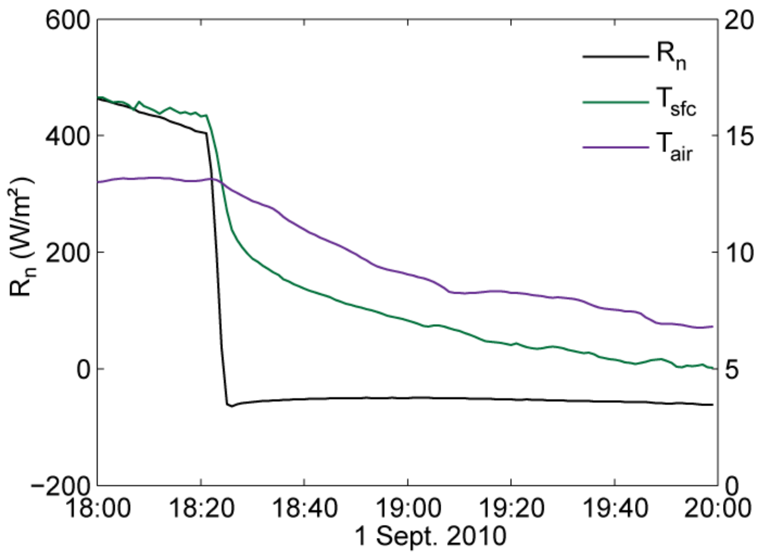
Surface's Response at Transition

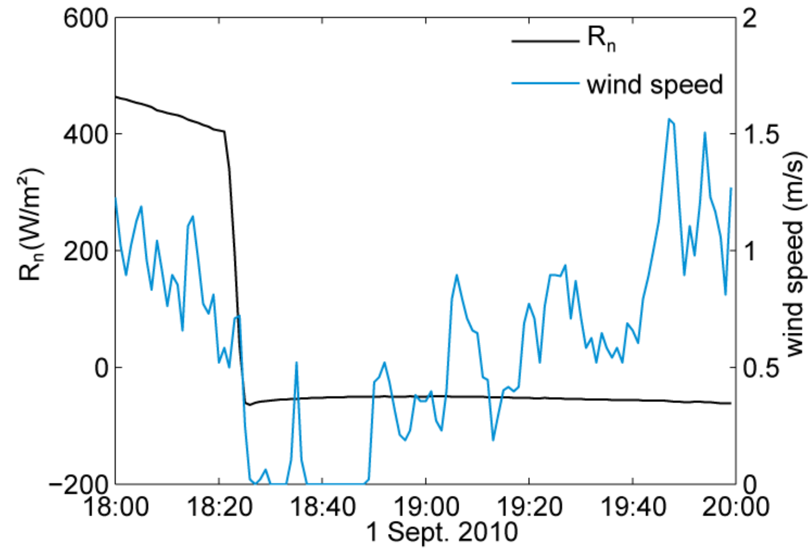
- bottom of the valley is shaded first
- dramatic drop in surface temperature when in the shade

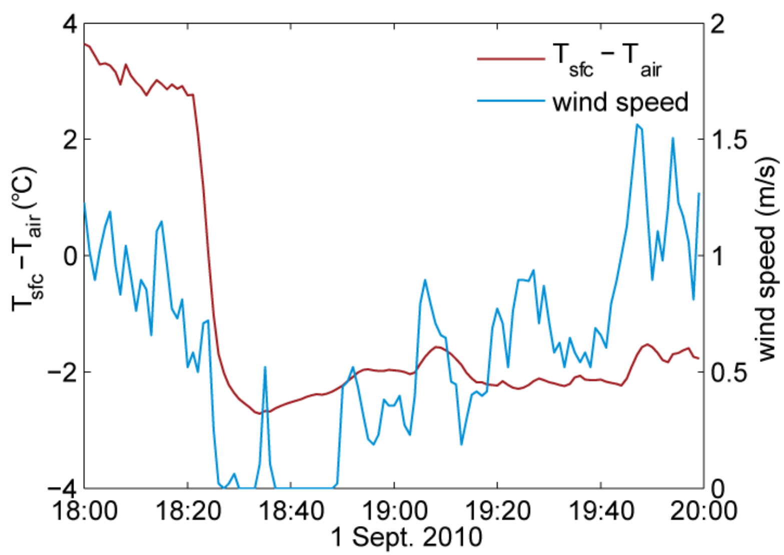


Atmospheric Response at Transition

Measurements at the energy balance station



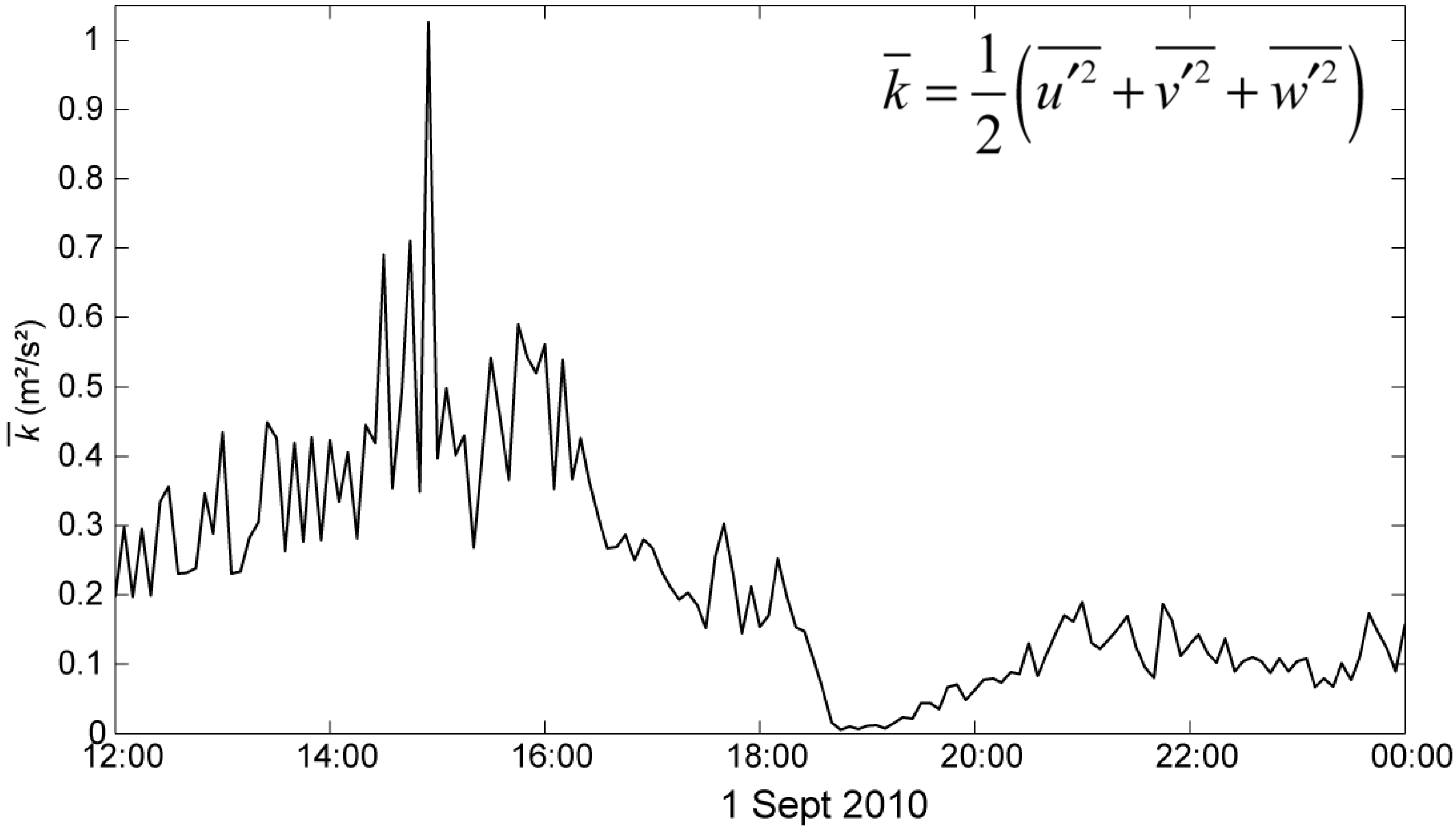




- quick response of T_{sfc}
- winds go to 0 m/s
- stratification builds up
- winds flow downslope

Turbulent Kinetic Energy (k)

Measurements from the lowest sonic (z = 1.5 m) at the 10-m tower



Turbulent Kinetic Energy Balance (dk/dt)

$$\frac{\partial \bar{k}}{\partial t} = \frac{g}{\bar{\theta}_v}\left(\overline{w'\theta_v'}\right) - \overline{u'w'}\frac{\partial \bar{U}}{\partial z} - \frac{\partial\left(\overline{w'k}\right)}{\partial z} - \frac{1}{\bar{\rho}}\frac{\partial\left(\overline{w'p'}\right)}{\partial z} - \varepsilon$$

neglect

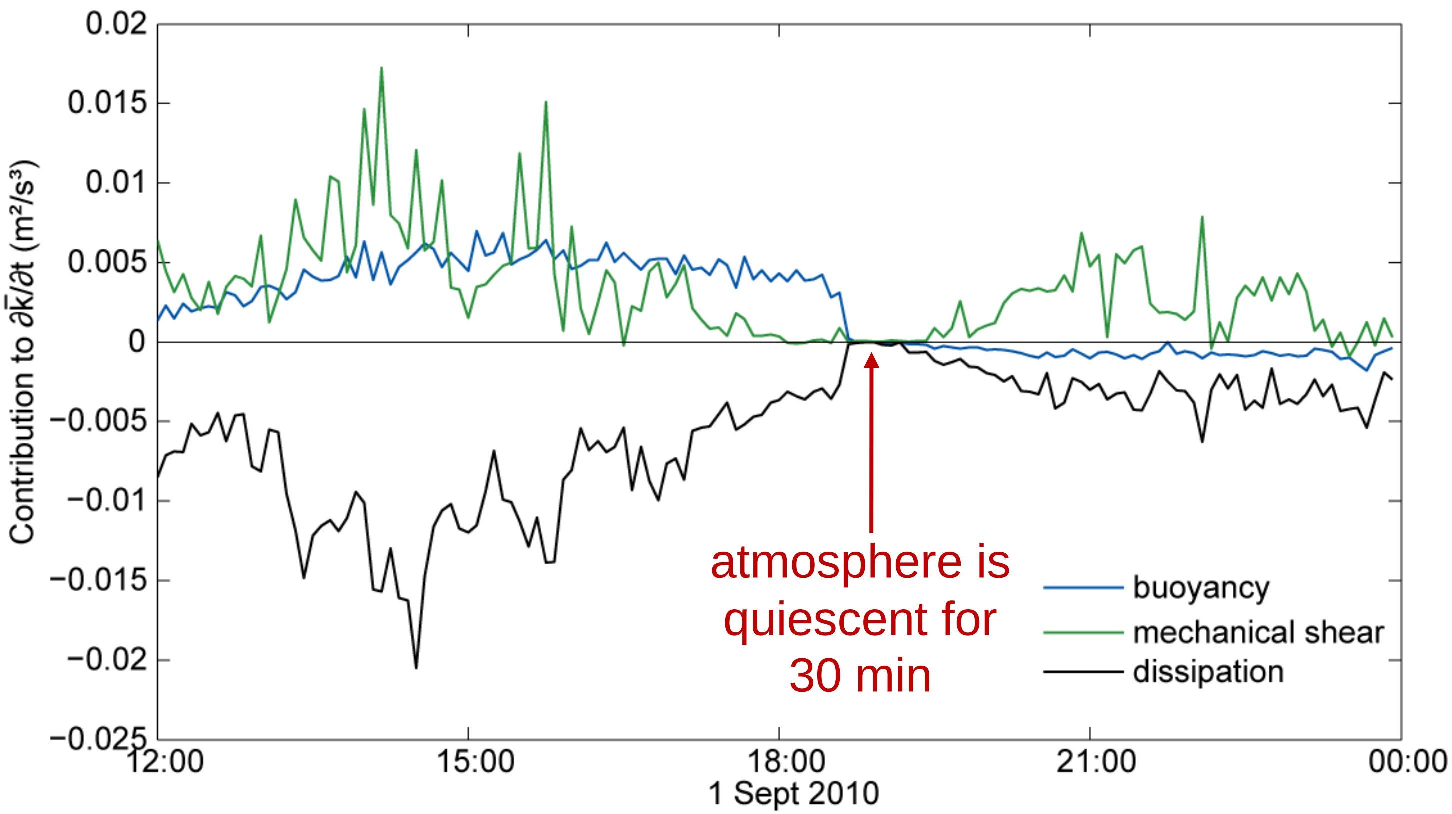
buoyancy

mechanical shear

dissipation

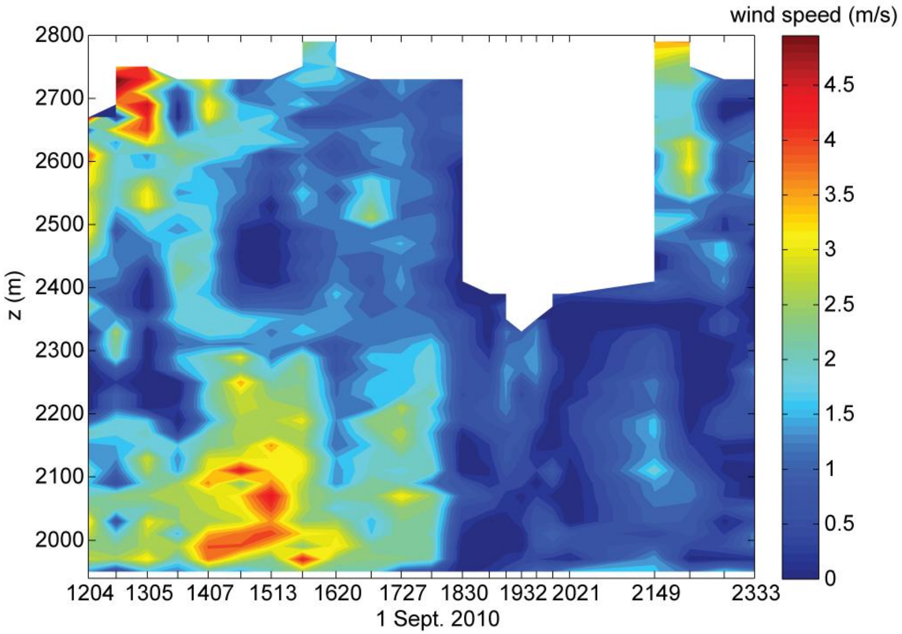
$$\varepsilon = 0.3634\left(r^{-1}\right)\left(D_{uu}\left(r\right)\right)^{3/2}$$

Measurements from the lowest sonic (z = 1.5 m) at the 10-m tower

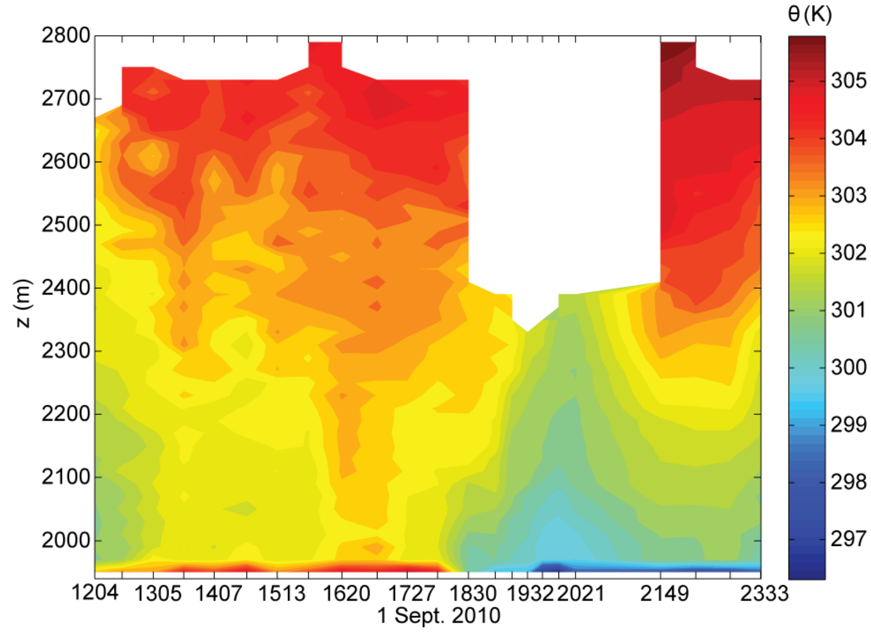


Vertical Structure

Wind speed profiles



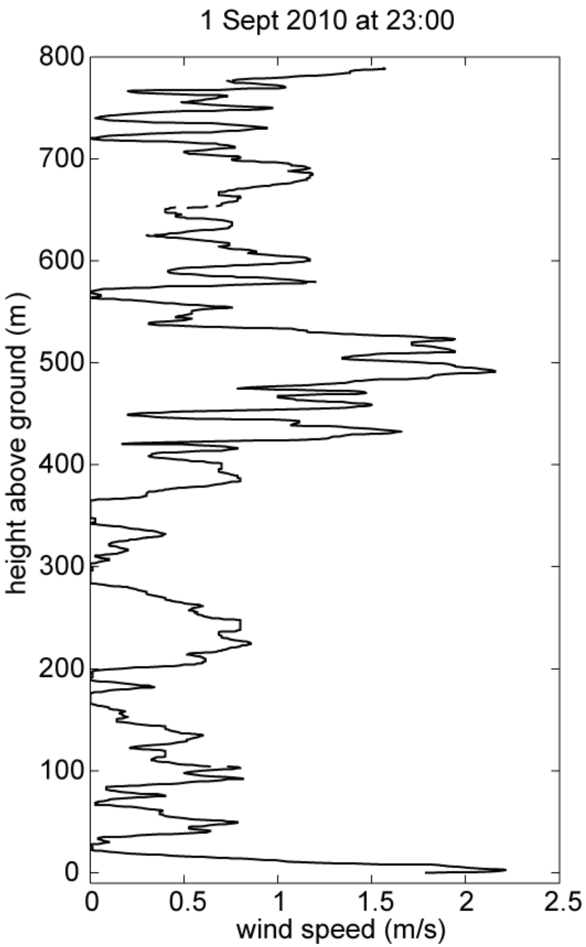
Potential temperature profiles

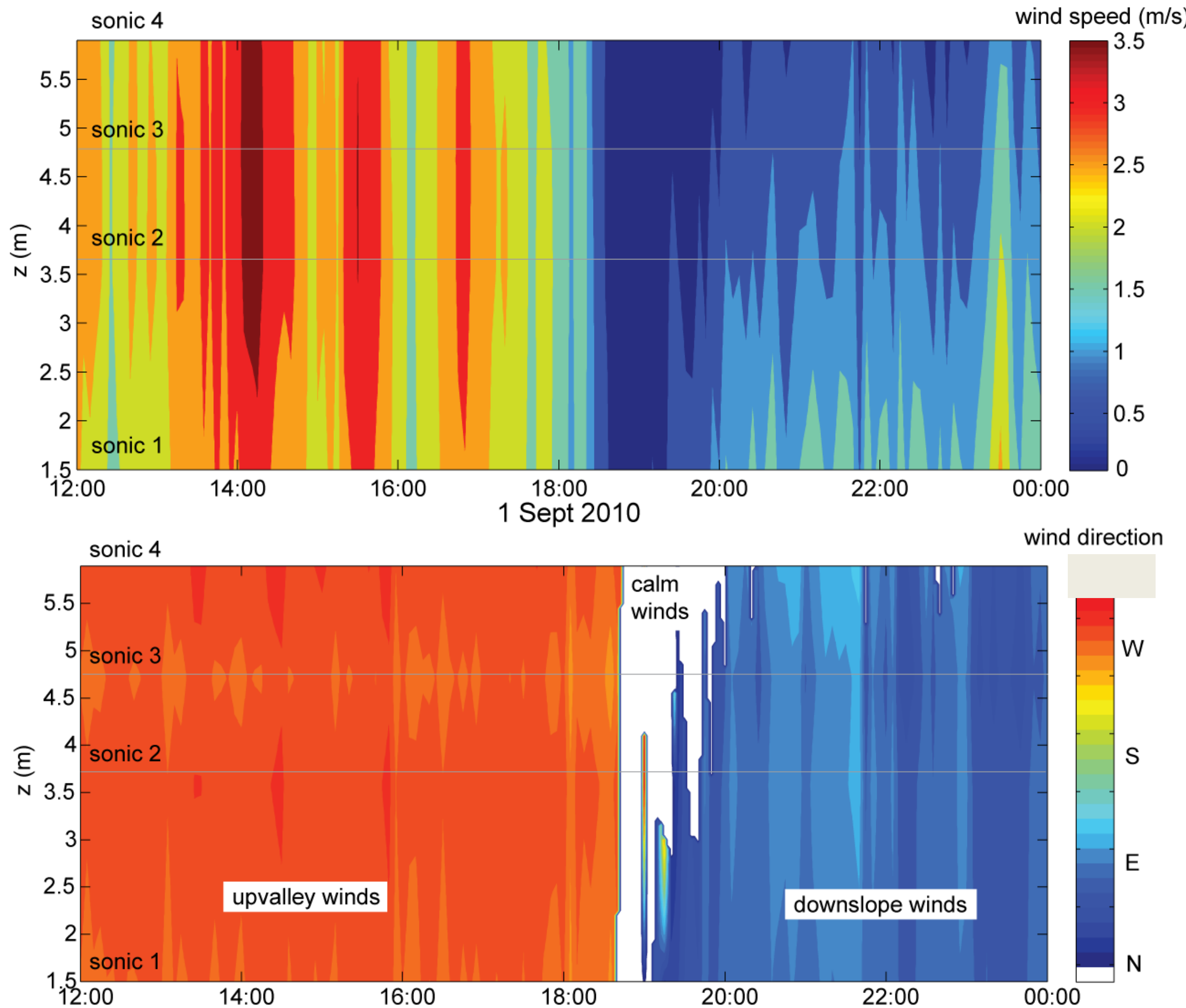


- midday upvalley wind maximum at 2050 m ASL
- calm winds for all z at evening transition
- shallow layer of downslope winds at night

- well-mixed daytime ABL
- h ≈ 2300 m
- mixing event at 21:00?

Nighttime Skin Flow





Conclusions

Evening transition in three steps

1) T_{sfc} reacts dramatically to rapid decrease in R_n
2) Atmosphere is quiescent for 30 min.
3) Build-up of stratification leads to very shallow downslope winds (skin flow)

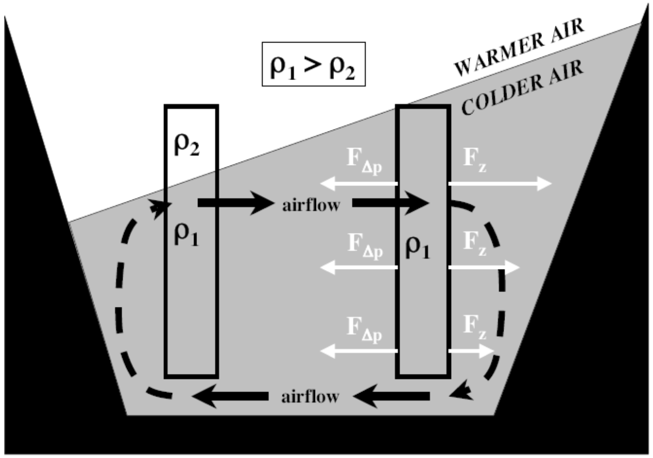
Future work

- Generalize approach for radiative days (ensemble means)
- Define important physical scales

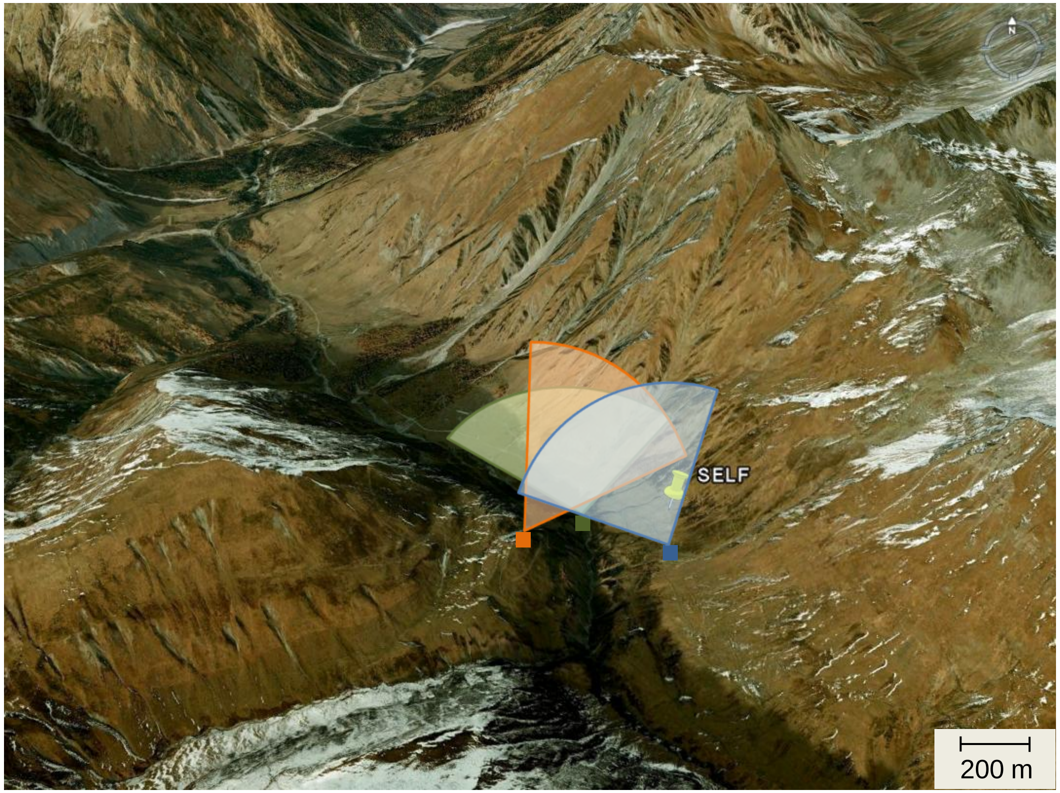
The 2011 Field Campaign

- **3 wind lidars** (*Halo Photonics*)

Curvature-induced secondary circulations

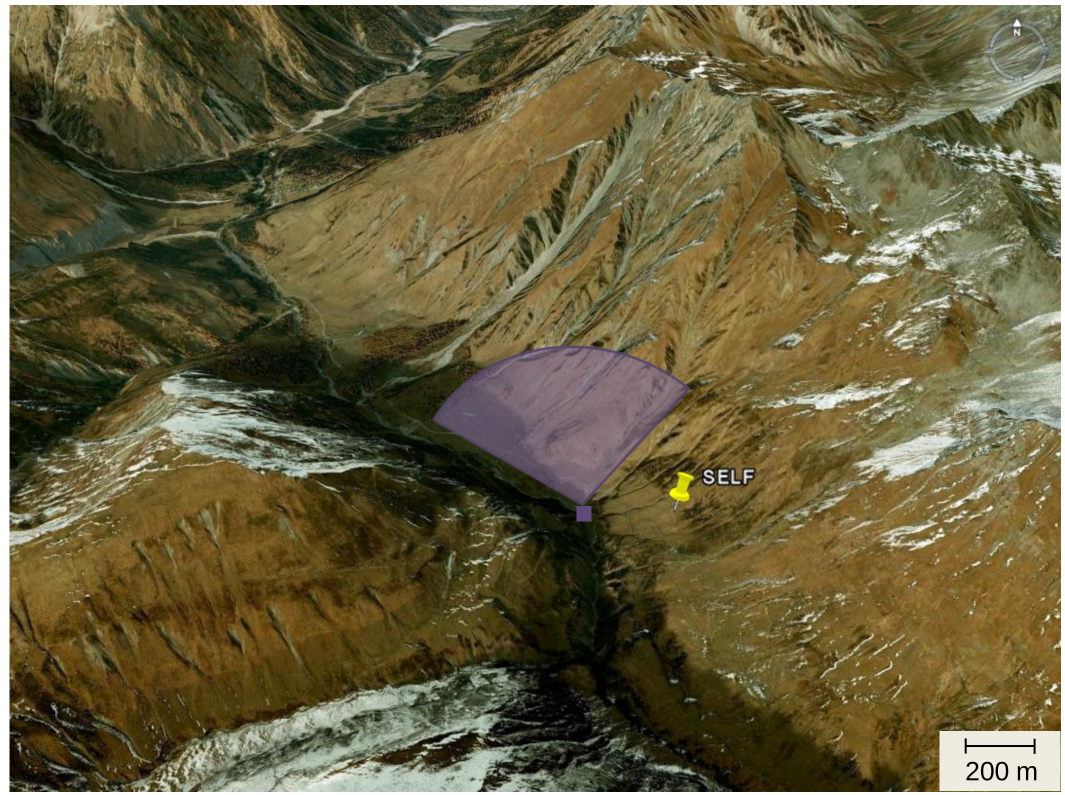


(Weigel and Rotach, QJRMS, 2004)

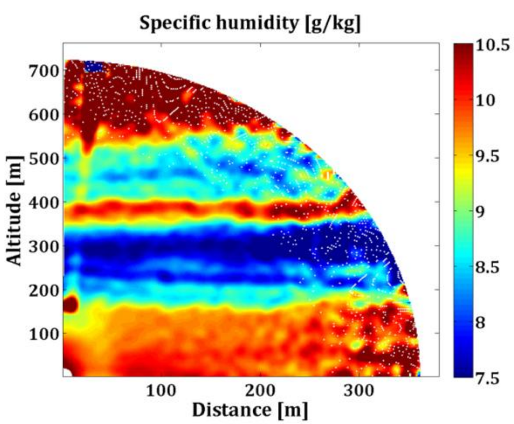


The 2011 Field Campaign

- **Raman lidar for water vapor and air temperature** (EPFL)



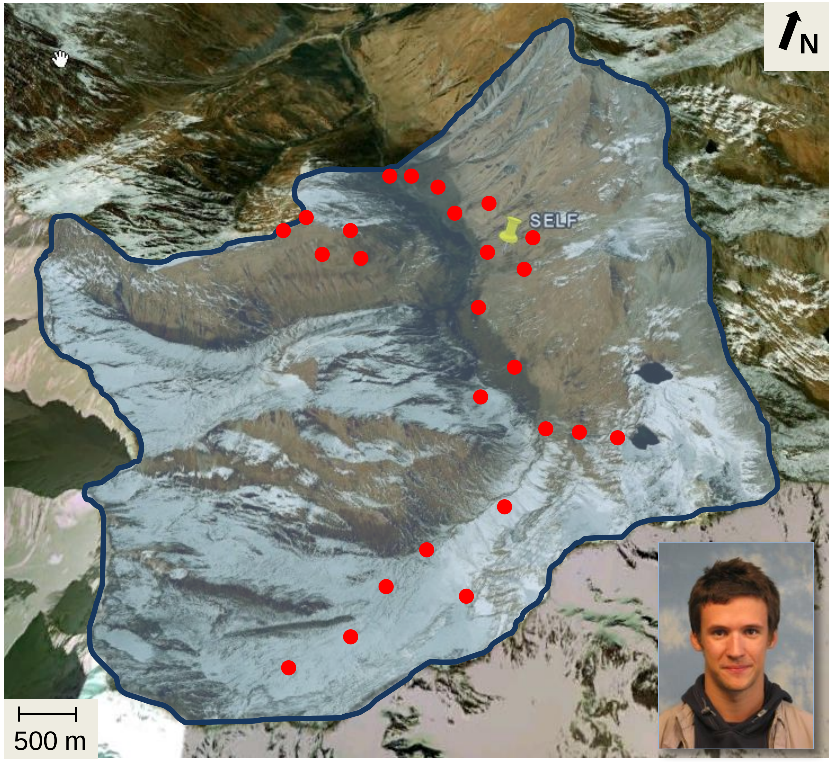
Atmospheric humidity stratification



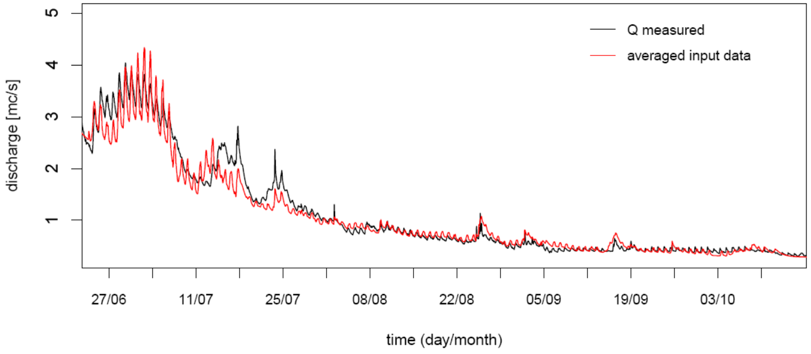
Seedorf (Swiss plateau), 30 Aug. 2008 at 00:30

The 2011 Field Campaign

- **A wireless sensor network of 25 Sensorscope stations**



Hydrologic modelling



(Simoni et al., to be submitted to WRR soon)

Acknowledgements

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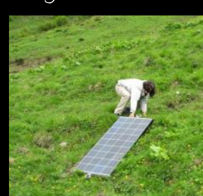

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Mike Pantic

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Valentin Simeonov

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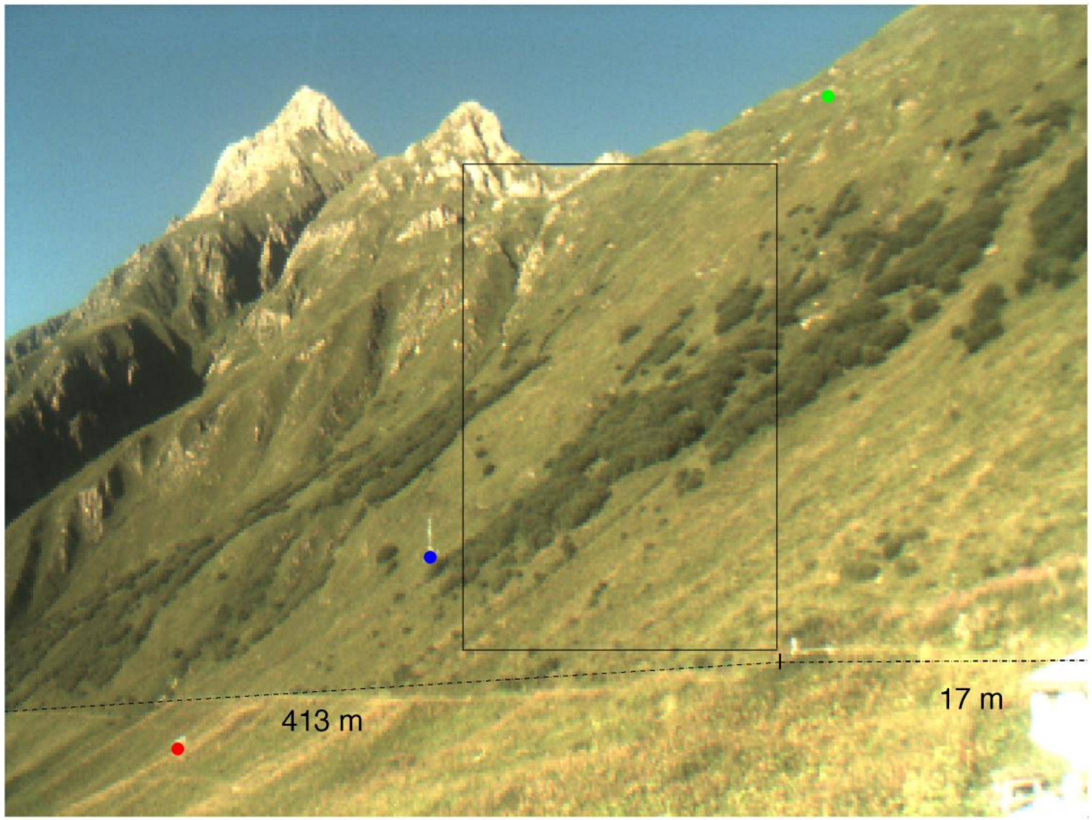
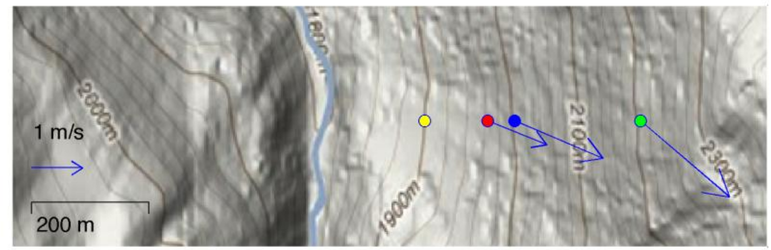
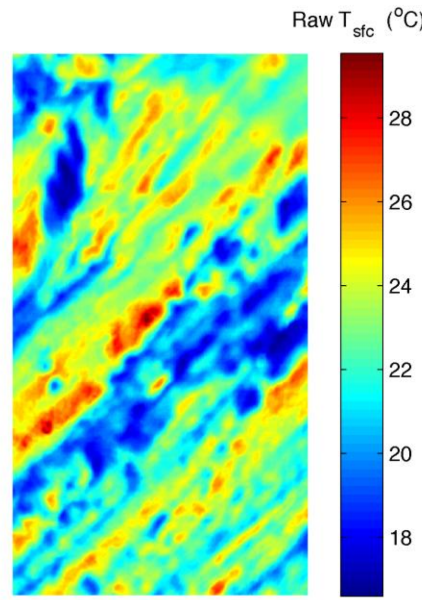
Thank you!

Val Ferret: 01-Sep-2010 18:00:25







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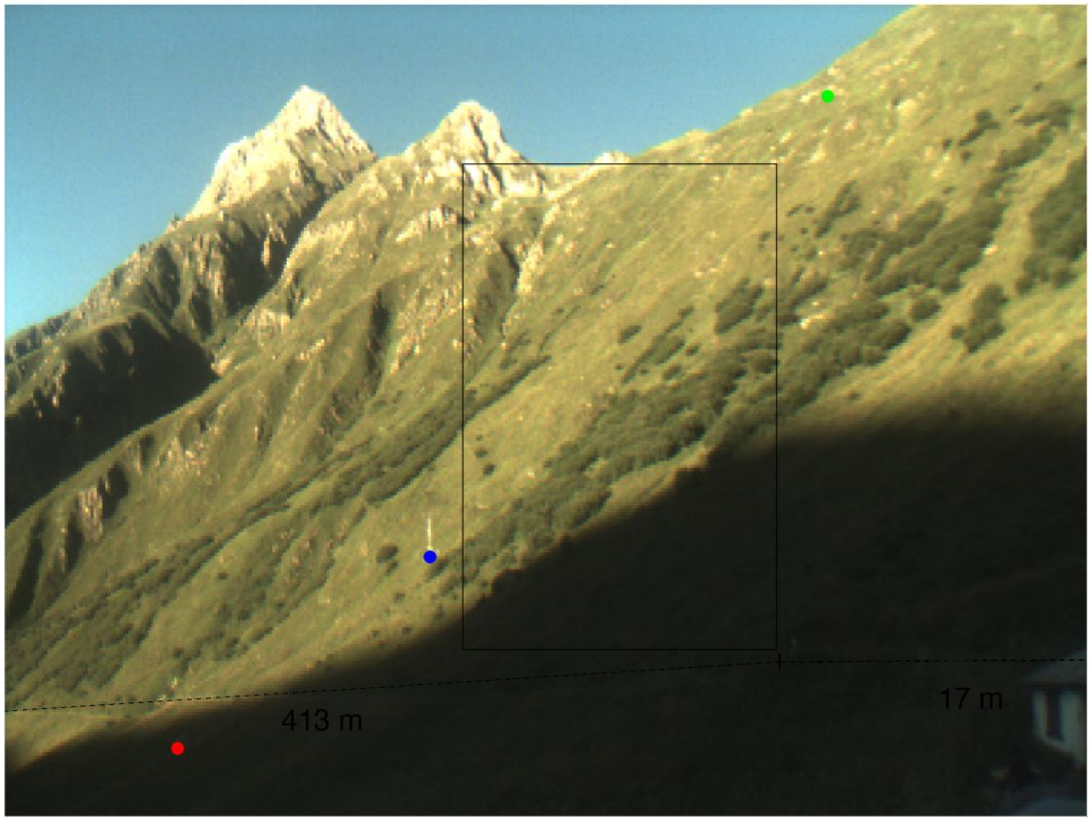

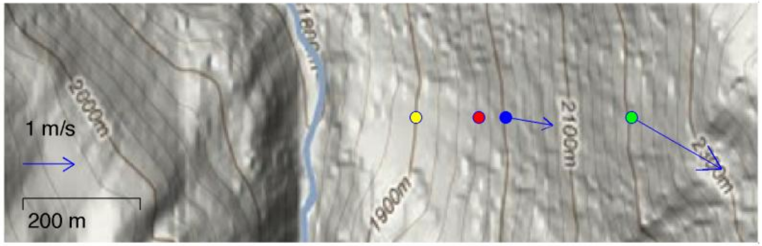

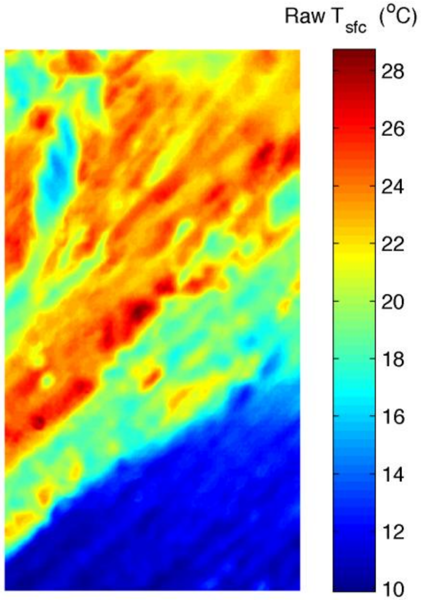

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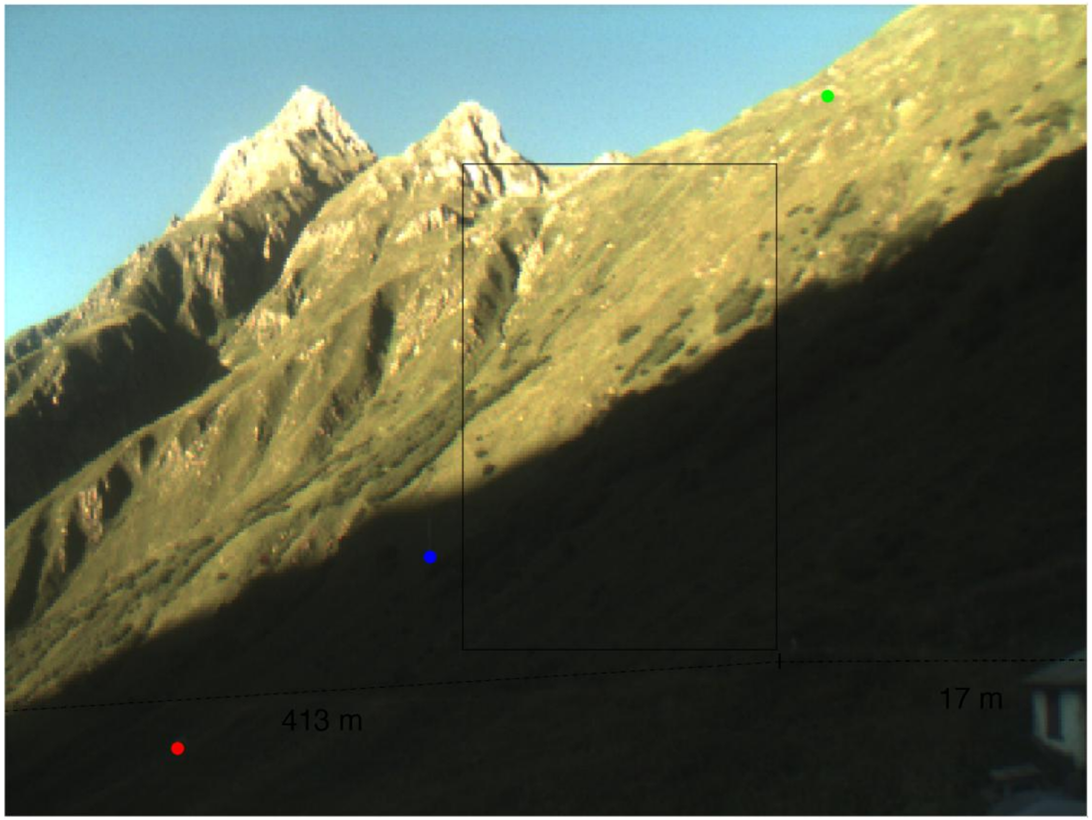

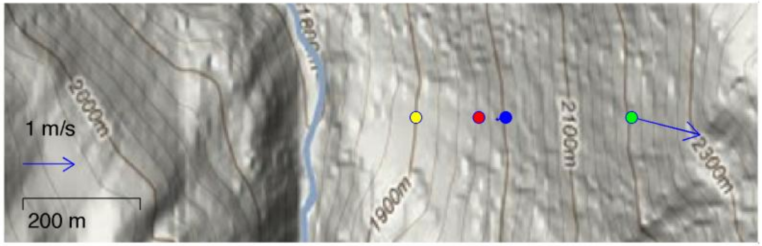

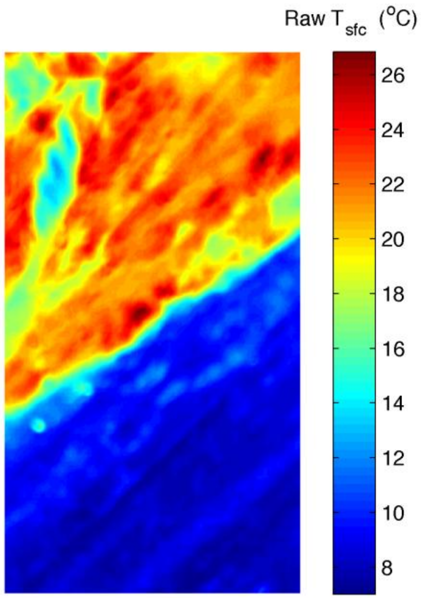

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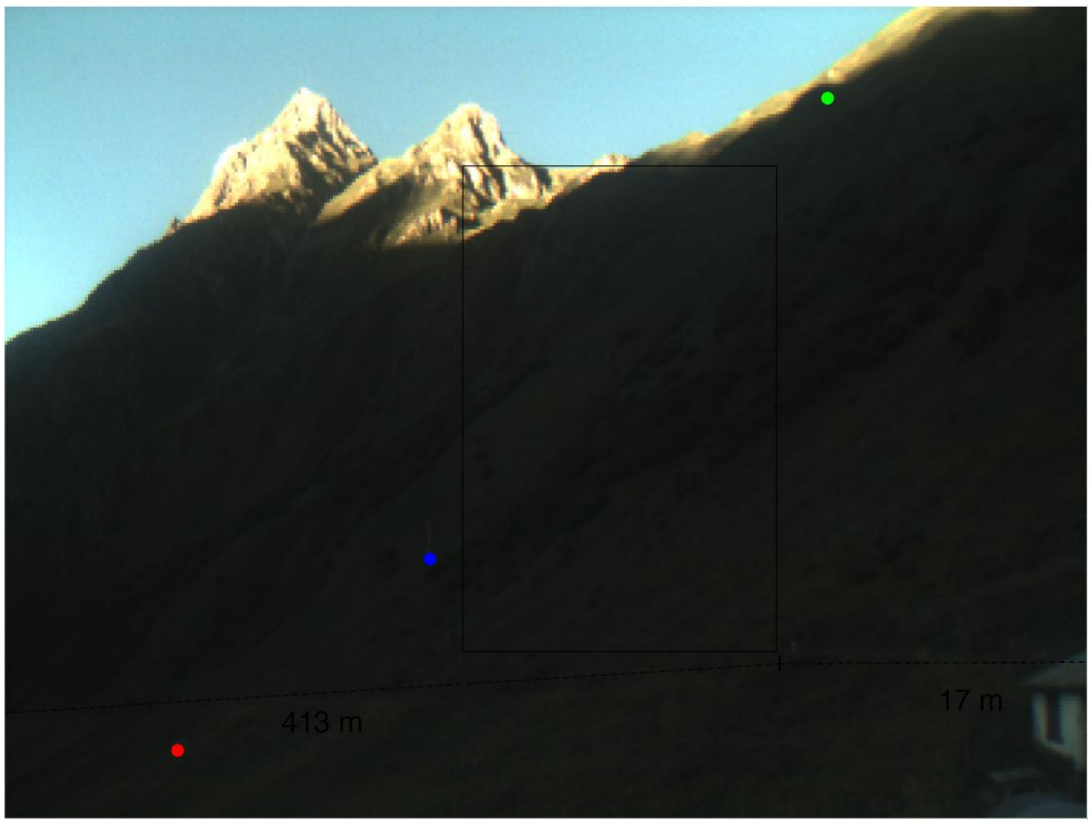
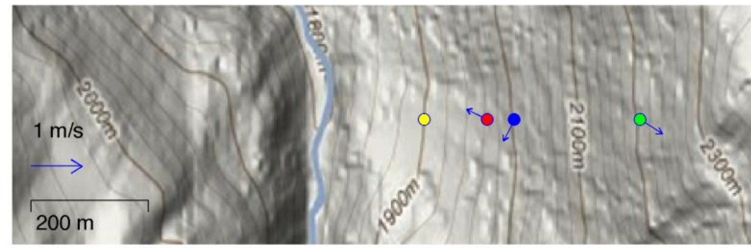
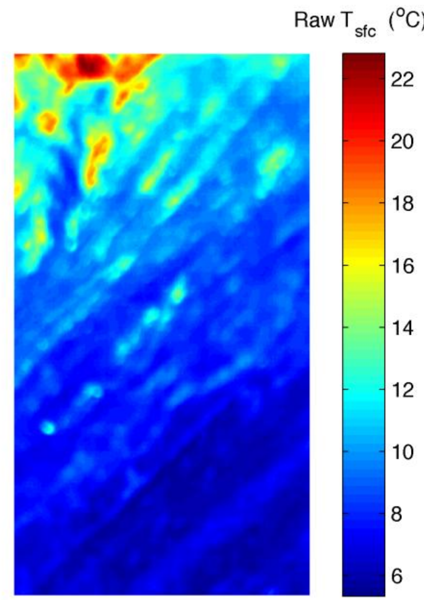
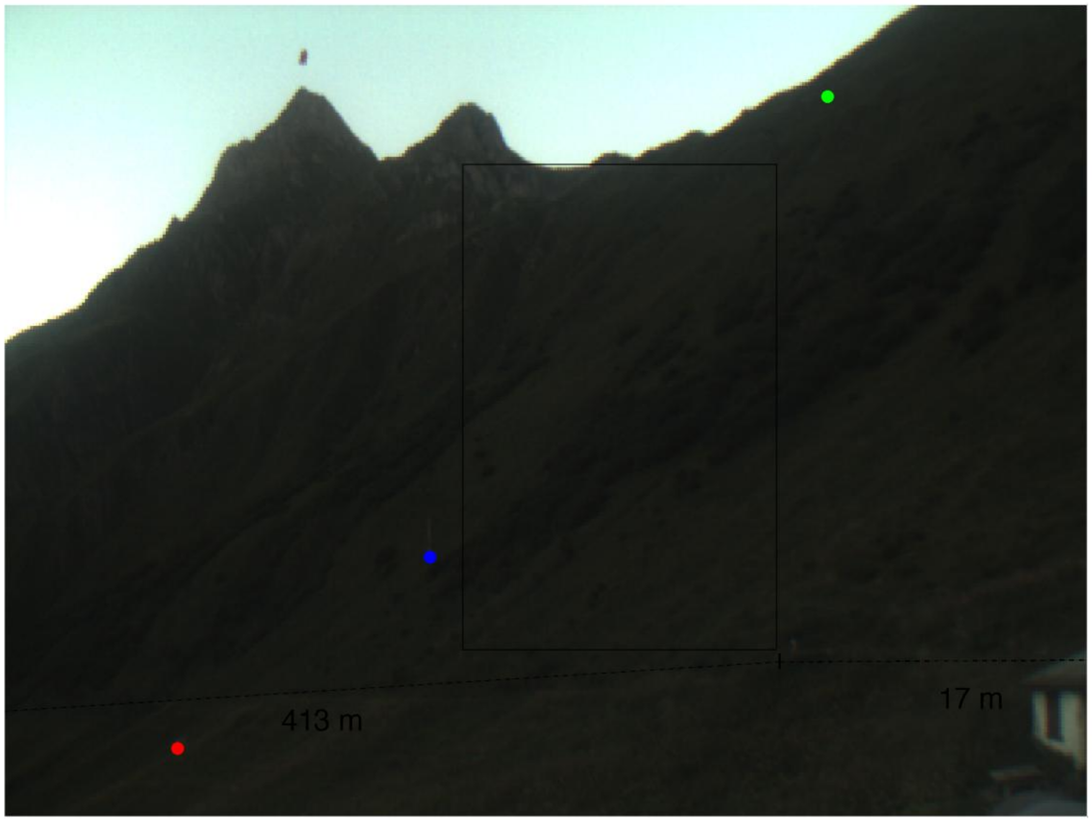
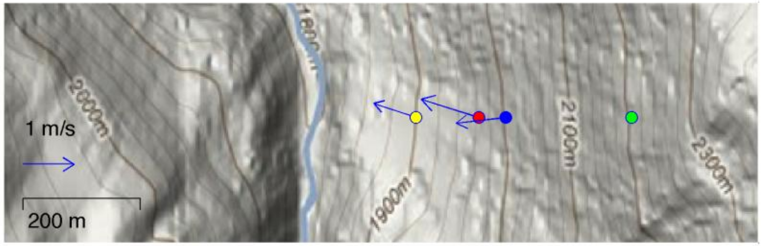


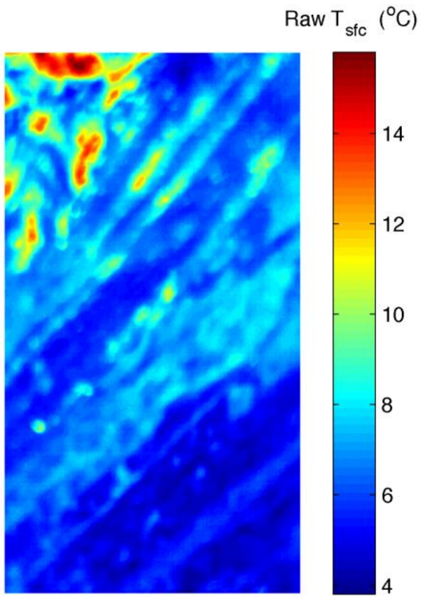




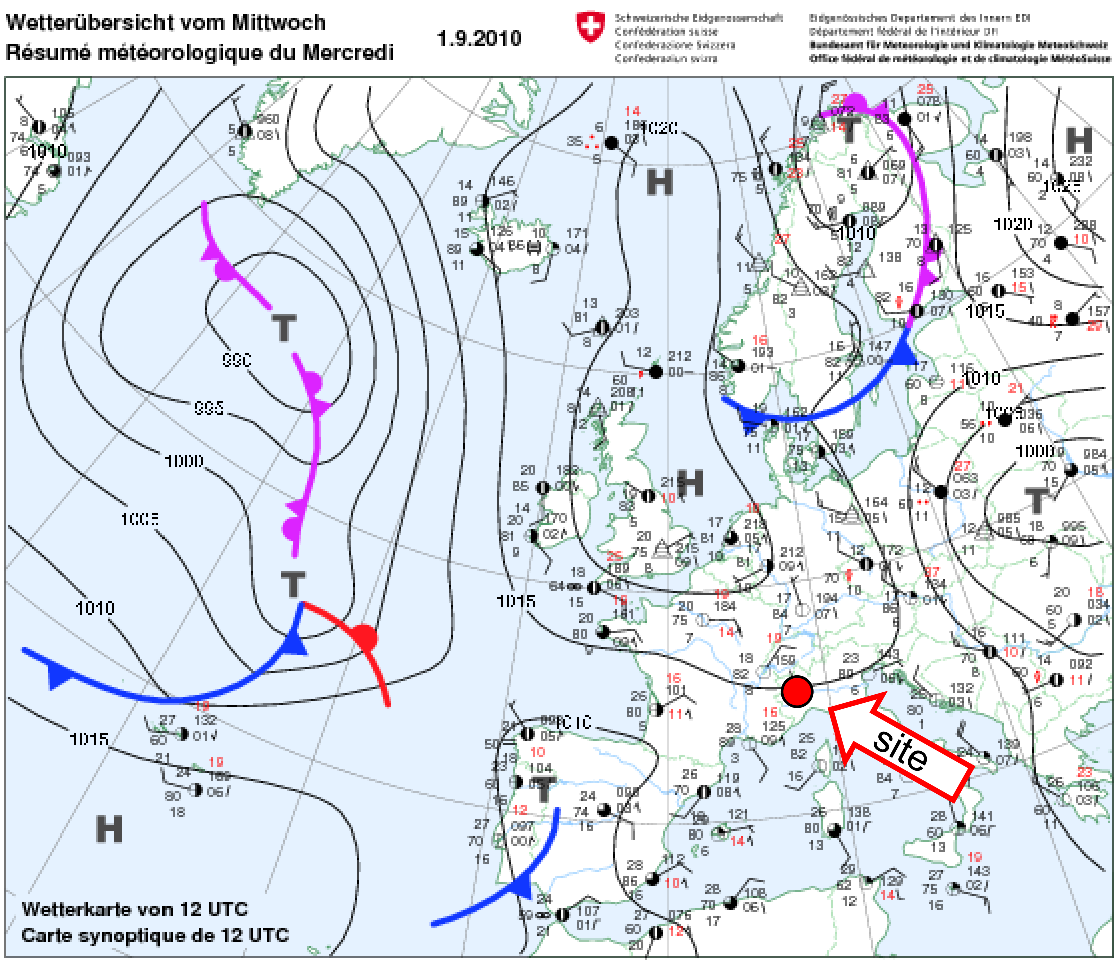
Val Ferret: 01-Sep-2010 20:00:25



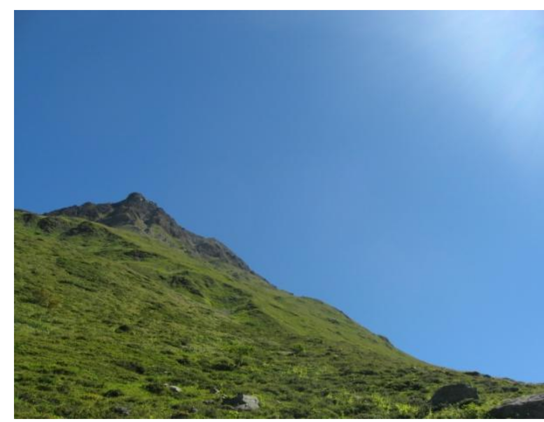




Weather Conditions on 1 Sept 2010



- clear sky conditions
- weak synoptic activity
- light northerly winds
- sunrise: 06:39
- sunset: 20:22
- mean daytime T_{air} = 9.1°C



field site at 13:40